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# **PUBLIC HEALTH RISK ASSESSMENT**

**Sola Optical USA, Inc. Site**

**Prepared for the U.S. Environmental  
Protection Agency**

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## EXECUTIVE SUMMARY

Between 1978 and 1985, Sola Optical USA, Inc. stored volatile organic compounds (VOCs) in six underground storage tanks at their site in Petaluma, California. In 1982, VOCs were detected in groundwater beneath the site and the underground storage tanks were removed in 1985. A groundwater extraction system was installed and has been in operation since 1988.

The purpose of this risk assessment is to characterize the potential health risks to a future onsite residents associated with VOCs detected in groundwater, soil, and soil-gas at the Sola Optical site. This assessment assumes continued operation of the groundwater extraction system. The risk assessment will be used to determine whether further remedial action is required at the Sola Optical site and, if so, to establish remedial action goals and objectives.

Twelve VOCs were identified as **chemicals of potential concern**. Five of these chemicals were detected in onsite groundwater, eleven in onsite subsurface soil, and seven in soil-gas samples taken at the site.

The **exposure assessment** evaluated potential exposure pathways (receptors and routes of exposure) for the chemicals of potential concern in groundwater, soil, and soil-gas. This assessment addresses potential risks from chemicals found at the site under a future onsite resident scenario. Pathways of exposure include groundwater as a drinking water source and exposure to VOCs which have been transported from groundwater or soil into household air. Routes of exposure include ingestion of drinking water, dermal contact, and inhalation of VOCs.

The **toxicological assessment** divided the twelve chemicals of concern by their carcinogenic or noncarcinogenic effects. Six chemicals of concern were classified as known, probable, or possible human carcinogens. The potential for carcinogenic effects was evaluated by estimating excess lifetime cancer risk. Noncarcinogenic risk was assessed by comparing the estimated daily intake of a chemical to the U.S. EPA estimated safe level of daily exposure, or reference dose.

The **risk characterization** evaluated the potential for carcinogenic effects from the chemicals of potential concern by estimating the excess lifetime cancer risk. Excess lifetime cancer risk is the incremental increase in the probability of developing cancer during one's lifetime over the background probability of developing cancer (i.e., if no exposure occurs). For example, a  $1 \times 10^{-6}$  excess lifetime cancer risk means that for every 1 million people exposed to the carcinogen throughout their lifetimes (which is typically assumed to be 70 years), the average incidence of cancer is increased by one additional case of cancer. Because of the health protective methods followed by the U.S. Environmental Protection Agency (U.S. EPA) in estimating cancer potency

factors, the excess lifetime cancer risks estimated in the assessment should be regarded as upper bounds on the potential cancer risks.

Excess lifetime cancer risks were calculated for the exposure pathways (routes and potential receptors) associated with the Sola Optical site. Estimated excess lifetime cancer risks due to exposure to groundwater were  $1 \times 10^{-4}$  and for inhalation of VOCs in household air,  $9 \times 10^{-6}$ .

Noncarcinogenic health risks were analyzed quantitatively by evaluating whether the daily intake exceeded the reference dose; the ratio of these is called the hazard index. The chemical-specific noncarcinogenic risks were added together to generate a total hazard index representing the chemicals found at the Sola Optical site. A hazard index of one or more indicates a potential concern. All exposure pathways had values of less than one for the hazard index.

There are many **uncertainties** associated with the risk assessment process. Because of these uncertainties conservative assumptions are used, and carcinogenic and noncarcinogenic risks are regarded as upper-bound risks. Actual risk may be lower.

## **1.0 INTRODUCTION**

### **1.1 PURPOSE AND SCOPE**

From 1978 to 1985, volatile organic compounds (VOCs) were stored in underground storage tanks at the Sola Optical USA, Inc. site in Petaluma, California. In 1982, VOCs were detected in groundwater near the underground tanks. The tanks were removed in 1985. A groundwater extraction system was installed and has been in operation at the site since August 1988.

The Sola Optical site was referred to the U.S. EPA for inclusion on the National Priorities List in 1987. In 1989, the U.S. EPA requested a remedial investigation (RI) and feasibility study (FS) for the site. Groundwater, soil, and soil-gas investigations have been conducted at the site by Van Houten Consultants, Inc. and Levine-Fricke to determine the extent of site contamination. This information has been used in the public health risk assessment (Section 3.0) to characterize the potential risks to a future onsite resident associated with contaminants present at the site. This risk assessment assumes continued operation of the groundwater extraction system.

### **1.2 ORGANIZATION**

The remainder of this report is presented in two sections. Section 2.0 describes the background of the site and presents a summary of the site investigations conducted to date. This section also includes air and groundwater modeling results. The data presented in Section 2.0 provide the basis for the public health risk assessment presented in Section 3.0.

The risk assessment methodology is presented in Appendix A, the risk calculations in Appendix B, and an evaluation of the ecological impact of the site in Appendix C.

## **2.0 SITE CHARACTERIZATION**

### **2.1 INTRODUCTION**

This section describes the Sola Optical site, the surrounding area, background information on site contamination and the physical characteristics of the site. Included in this section is a summary of the sampling conducted at the site to determine the extent of contamination in groundwater and soil and modeling results used to determine contaminant transport.

### **2.2 SITE BACKGROUND**

Sola Optical is located on a 35-acre site in Petaluma, California. As shown on Figure 2-1, the site is bordered on the north by Lakeville Highway, on the west by Cader Lane, and on the south and east sides by open fields. Adobe Creek lies approximately 0.3 miles to the west of the site and the Petaluma River is approximately 1 mile southwest of the site.

Sola Optical has been manufacturing optical lenses at the site since 1978 (Levine-Fricke, 1990). The manufacturing facilities, warehouse facilities, and offices are contained in a large one-story building on the site. A paved parking lot surrounds the building. The layout of the site is shown on Figure 2-2.

From 1978 to 1985, Sola Optical stored VOCs (acetone, methanol, and 1,1,1-trichloroethane) in six 1,000-gallon underground tanks at the site (Levine-Fricke, 1990). These tanks, which were 4.5 feet in diameter and 10.5 feet long, were located near the southwest corner of the manufacturing building approximately 6 feet below ground surface (Levine-Fricke, 1990) (see Figure 2-2). In 1982, VOCs were detected in groundwater beneath the site near the location of the underground storage tanks. In 1985, Sola Optical removed the six tanks along with some of the soil from the sides and bottom of the excavated area (Levine-Fricke, 1990). In 1987, a groundwater extraction and treatment system was installed by Sola Optical with the approval of the Regional Water Quality Control Board (RWQCB)--San Francisco Region (Levine-Fricke, 1990). The extraction system has been operating at the site since 1988.

### **2.3 PHYSICAL CHARACTERISTICS OF THE SITE**

According to Levine-Fricke (1990), the surface of the Sola Optical site is relatively flat, sloping to the southwest at a rate of approximately 50 feet per mile. Surface elevations at the site range from approximately 30 feet above Mean Sea Level (MSL) in the northeastern portion of the site to approximately 18 feet above MSL in the southwest portion of the site (Levine-Fricke, 1990).

Geological investigations conducted at the Sola Optical site show that the shallow sediments, less than approximately 80 to 100 feet, consist mainly of interbedded clays, silts, sands, and gravel (Levine-Fricke, 1990). Clay intervals, approximately 30 to 60 feet thick, are encountered below 100 feet. According to Levine-Fricke (1990), these clay intervals are relatively continuous for distances of hundreds of feet. Contained in these clay intervals are layers of silt, sand, and gravel of various thickness.

Groundwater at the site is encountered at elevations ranging from approximately 9 to 15 feet below ground surface. Groundwater flow at the site is generally toward the southwest (Levine-Fricke, 1990). According to Levine-Fricke (1990), groundwater measurements taken at the site since 1986 show that seasonal fluctuations in water levels have little effect on the pattern of groundwater flow in the area.

## **2.4 SUMMARY OF SITE INVESTIGATIONS**

This section describes the groundwater and soil sampling that has been conducted at the Sola Optical site. This discussion is based primarily on information contained in the Remedial Investigation Report from Sola Optical U.S.A., Inc. Site (Levine-Fricke, 1990).

### **2.4.1 GROUNDWATER**

Levine-Fricke has conducted groundwater monitoring at the Sola Optical site since September 1986. Details on the monitoring well installation and a summary of the groundwater sampling results from 1986 to 1990 are presented in the Levine-Fricke Remedial Investigation Report (1990). This assessment will focus on the April-May and August-September, 1990 groundwater sampling results from Levine-Fricke Monitoring Wells LF-1 through LF-28. The locations of Monitoring Wells LF-1 through LF-28 are shown on Figure 2-3.

Wells installed by a previous contractor (Wells W-1 through W-33), along with Levine-Fricke groundwater monitoring results prior to April 1990, lacked EPA oversight and approved Quality Assurance Project Plans (QAPP). In addition, the RWQCB has expressed concern over some of the W-wells based on uncertainties regarding well construction data and concern that perforated well casings did not cover the full interval of the sediments being investigated (Personal Communication, 1991a). As part of Sola's present monitoring program, several of the W-wells are being monitored. Data was collected from wells W-12 through W-15, W-21, W-24, W-26 through W-28, W-30, and W-31 during the April-May and August-September, 1990 groundwater sampling events. The location of these wells are shown in Figure 2-3. The effect of including these results in the risk calculations has been addressed separately in Section 3.5, Health Risk Assessment.



According to Levine-Fricke (1990), Monitoring Wells LF-1 through LF-28 were installed at depths of shallow (up to approximately 30 ft), intermediate (up to approximately 60 ft), deep (up to approximately 100 ft), deeper (up to approximately 200 ft), and deepest (>200 ft). Shallow and intermediate Monitoring Wells LF-1 through LF-11 were installed between September and April 1987. Deep Monitoring Wells LF-12 through LF-18 and shallow Wells LF-19 through LF-20 were installed during June and July 1990. The remaining wells, LF-21 through LF-28, were installed in April 1990. Wells LF-25 and LF-28 are shallow wells, LF-21, LF-22, LF-23, and LF-26 are intermediate-depth wells, LF-24 is a deep well, and LF-27 is at the deepest depth (240 feet below ground surface). The depths of the monitoring wells are summarized in Table 2-1. As shown on Figure 2-3, Wells LF-8 through LF-11, LF-23, and LF-24 are located offsite.

In 1990, Sola Optical conducted their annual and semi-annual groundwater sampling events between April 19 and May 4 and August 27 and September 11, respectively (Levine-Fricke, 1990). A U.S. EPA representative was present during the sampling on May 2 and 3, 1990 of Wells LF-13, LF-17, LF-21, LF-24, and LF-27 and collected split samples from these wells. The U.S. EPA representative also collected split samples from Wells LF-17, LF-25, LF-26, and LF-28 on August 29, 1990. Groundwater samples were analyzed using U.S. EPA Methods 601 (purgeable halocarbons), 8010 (halogenated volatile organics), and 8240 (volatile organics). Table 2-2 lists all chemicals sampled for, the number of samples taken, and the number of detections for all LF-wells. Groundwater concentrations for all detected chemicals in LF-wells are presented in Table 2-3.

As shown in Table 2-2, only five chemicals were detected in LF-wells during the annual and semiannual 1990 groundwater sampling events; 1,1-dichloroethane (1,1-DCA), 1,1-dichloroethene (1,1-DCE), 1,1,2-trichloro-1,2,2-trifluoroethane (Freon-113), toluene, and 1,1,1-trichloroethane (1,1,1-TCA). Monitoring wells LF-1 and LF-11 were not sampled in 1990. According to U.S. EPA Region IX (1990), Monitoring Well LF-27 is not considered a valid-quality sampling point because of poor hydraulic connections with aquifers at the same depth.

Four of these five chemical were sampled for and detected in the W-wells during the annual and semi-annual groundwater sampling events. These four chemicals are 1,1-DCA at a maximum of 0.28 mg/l, 1,1-DCE at a maximum of 1.4 mg/l, Freon 113 at a maximum of 0.007 mg/l, and 1,1,1-TCA at a maximum of 0.22 mg/l. In addition to these chemicals, six other chemicals were detected. Additional chemicals detected included 1,2-DCA (at a maximum of 0.002 mg/l), trichloroethene (TCE) (at a maximum of 0.03 mg/l), chloroform (at a maximum of 0.002 mg/l), 1,1,2-TCA (at a maximum of 0.003 mg/l), tetrachloroethene (PCE) (at a maximum of 0.002 mg/l), and trichlorofluoromethane (Freon 11) (at a maximum of 0.009 mg/l). Of these additional six chemicals, all but Freon 11 were detected in less than 5 percent of the total groundwater samples taken during the sampling period. The maximum concentrations for all chemicals detected in W-wells were found in wells W-14 and W-28. Both wells

fall within the current capture area of the groundwater extraction system. Groundwater concentrations for all chemicals detected in the W-wells are presented in Table 2-4.

For the annual and semiannual 1990 groundwater sampling events, Levine-Fricke (1990) estimated the areal extent of VOC contamination at greater than corresponding state and federal Maximum Contamination Limits (MCLs). Figure 2-4 illustrates the extent of contamination greater than MCLs in shallow, intermediate, deep, and deeper-depth groundwater. These contours are based on information from all groundwater wells, historic and LF-wells. Based on Table 2-3, 11 of 26 LF monitoring wells were found to contain VOCs above the detection level. Seven of these wells fall within the proposed contours where VOC concentrations exceed MCLs. Four of the monitoring wells, LF-6, LF-25, LF-26, and LF-28, contain VOCs at concentrations below MCLs. Federal and state MCLs for the five chemicals detected in the LF monitoring wells are listed in Table 2-4.

Two private wells exist in the vicinity of the Sola Optical site, the Stero well located approximately 1,000 feet west (downgradient) of the site and the Crandell well located approximately 1,500 feet southwest (downgradient) of the site. Use of the Stero well was discontinued in April 1990, and Sola Optical removed the pumping system from the well in May 1990 (Levine-Fricke, 1990). The Crandell well was abandoned on October 5, 1990 (Levine-Fricke, 1990). Both locations are now using City-supplied water.

The City of Petaluma Station 5 well, located 300 feet north of the site at Lakeville Highway and Frates Road (Figure 2-2), discontinued operation in June 1988. This well has a screened interval from 180 to 512 feet below ground surface. Before ceasing operation, the Station 5 well was sampled from November 1986 to May 1988 by both MultiTech Laboratories and Levine-Fricke. The results of these sampling activities are presented in Table 2-6. As shown in Table 2-6, chemicals detected in this well included 1,1-DCA (at a maximum of 0.0009 mg/l), 1,1-DCE (at a maximum of 0.002 mg/l), 1,1,1-TCA (at a maximum of 0.0032 mg/l), 1,2-DCA (at 0.001 mg/l), bromodichloromethane (at 0.0025 mg/l), chloroform (at 0.002 mg/l), and dibromochloromethane (at 0.0022 mg/l).

Operations have also been discontinued at the Sola-City well located on the northern portion of the Sola Optical site near Lakeville Highway (Figure 2-2). This well has a screened interval from 60 to 280 feet below ground surface. Groundwater samples have been taken from this well on an annual basis since 1986. Samples taken from this well were analyzed using U.S. EPA Method 601 (purgeable halocarbons). The only chemical detected was TCE in August 1987 at a concentration of 0.0007 mg/l (Levine-Fricke, 1990).

Sola Optical has entered into written agreement with the City of Petaluma to ensure that the Station 5 and the Sola-City wells will remain closed until the city is satisfied that further investigations are not needed and that there is no threat of drawing con-

taminated water into these wells. The city may operate the wells for specifically defined periods of time for water sampling and during a period of natural disaster.

## **2.4.2 SOIL**

In addition to groundwater monitoring, both soil and soil-gas samples have been taken at the Sola Optical site. This section summarizes the results of these investigations.

### **2.4.2.1 Soil Sampling**

Soil samples were taken by Van Houten Consultants, Inc. in July 1985 during the excavation of the underground storage tanks. A total of 22 soil samples were taken from the excavated pit after the gravel backfill and an additional 3 feet of native soils from the sides and bottom of the tank had been removed (Levine-Fricke, 1990). Samples were analyzed using U.S. EPA Methods 8010 (halogenated volatile organics) and 8020 (aromatic volatile organics). The results of this analysis showed concentrations of acetone ranging from 1.1 to 54 mg/kg (detected in 10 out of 22 samples) and concentrations of 1,1-DCE (0.010 mg/kg) and trans-1,2-DCE (0.005 mg/kg) from the sidewalls of the excavation pit. No other chemicals were detected above detection limits (Levine-Fricke, 1990).

Two additional feet of soil were excavated by Van Houten Consultants, Inc. from the eastern wall of the former tank area in August 1985 (Levine-Fricke, 1990). The eastern wall was the location of the highest acetone concentrations. Three soil samples taken from the eastern wall of the newly excavated area were analyzed using U.S. EPA Method 602 (purgeable aromatics) (Levine-Fricke, 1990). Acetone was found in all three samples in concentrations ranging from 70 to 200 mg/kg (Levine-Fricke, 1990). In addition, benzene, toluene, xylene, ethylbenzene, chlorobenzene, and dichlorobenzene were detected in concentrations ranging from 0.002 mg/kg (chlorobenzene) to 0.230 mg/kg (xylene) (Levine-Fricke, 1990).

Four shallow soil samples (less than 3 feet deep) were taken by Levine-Fricke in 1988 near the location of the former storage tanks (Levine-Fricke, 1990). Samples were analyzed using U.S. EPA Method 8010 (halogenated volatile organics). Chemicals detected in the four borings included DCA (at a maximum of 0.013 mg/kg), DCE (at a maximum of 0.018 mg/kg), 1,1,1-TCA (at a maximum of 0.001 mg/kg), PCE (at 0.006 mg/kg), 1,1,2-TCA (at 0.005 mg/kg), and TCE (at 0.005 mg/kg) (Levine-Fricke, 1990). Samples were not analyzed for benzene, ethylbenzene, toluene, or xylene.

In April 1990, Levine-Fricke took six soil borings at the site (Levine-Fricke, 1990). The locations of the six soil borings, labelled SB-1 through SB-6, are shown on Figure 2-5. According to Levine-Fricke (1990), boring locations were chosen according to past chemical activities at the site. SB-1 and SB-2 are located near the eastern wall of the former excavation pit in the vicinity of the former tank fill pipes. SB-3 and SB-4 are located downgradient from the location of the former underground tanks. SB-5 and SB-6 are located near the paved area of the site (Levine-Fricke, 1990). The gravelly

sandy silt found at a two foot depth in SB-1 suggests that this sample was taken in the backfill of the former tank excavation area (Levine-Fricke, 1990).

Two samples were taken from each of the six soil borings. Samples were taken from depths of 3.5 to 4.5 feet below ground surface and 7.5 to 9.5 feet below ground surface. Soil samples were analyzed using U.S. EPA Method 8010 (halogenated volatile organics) and Method 8240 (volatile organics). The results of these analyses are presented in Table 2-7. Eleven chemicals were detected in soil: acetone, butanone, 1,1-DCA, 1,2-DCA, 1,1-DCE, 4-methyl-2-pentanone, PCE, toluene, 1,1,1-TCA, 1,1,2-TCA, and TCE. A U.S. EPA representative collected split samples from borings SB-3 and SB-6. The results of the split samples are also shown in Table 2-7. Five chemicals detected in the 1985 soil sampling (benzene, chlorobenzene, dichlorobenzene, ethylbenzene, and xylene) were analyzed for, but not detected, in the 1990 soil samples from the excavation area. These chemicals have not been included in this assessment.

#### **2.4.2.2 Soil-Gas Sampling**

Soil-gas sampling was conducted in 1986 at the Sola Optical site by Tracer Research Corporation (TRC) under the supervision of Levine-Fricke (1990). Samples were taken from 48 locations throughout the unpaved field southwest of the Sola Optical facility at depths ranging from 3 to 5 feet. The purpose of the sampling was to determine the VOC migration in shallow groundwater and to select locations for groundwater monitoring and extraction wells (Levine-Fricke, 1990). The samples were analyzed for chloroform, carbon tetrachloride, 1,1-DCA, 1,1-DCE, PCE, 1,1,1-TCA, and TCE. Chloroform was detected at a maximum of 0.8 µg/l, carbon tetrachloride at a maximum of 0.002 µg/l, 1,1-DCA at a maximum of 130 µg/l, 1,1-DCE at a maximum of 8 µg/l, PCE at a maximum of 25 µg/l, 1,1,1-TCA at a maximum of 250 µg/l, and TCE at a maximum of 25 µg/l. The highest concentrations were found approximately 70 feet downgradient from the location of the former underground storage tanks (Levine-Fricke, 1990).

Soil-gas sampling was conducted again in April, 1990 by TRC under the supervision of Levine-Fricke (1990). Forty locations, labelled SG-1 through SG-40 on Figure 2-6, were sampled at depths ranging from 2 to 9 feet. All samples were analyzed for acetone, 1,1-DCA, 1,1-DCE, Freon 113, PCE, 1,1,1-TCA, and TCE. According to Levine-Fricke (1990), these chemicals were selected based on chemicals previously detected in soils near the location of the former underground storage tank and based on the chemicals reportedly stored in the former tanks. As shown on Figure 2-6, acetone was detected at a maximum concentration of 0.1 µg/l, 1,1-DCA at a maximum concentration of 12 µg/l, 1,1-DCE at a maximum concentration of 68 µg/l, Freon 113 at a maximum concentration of 0.6 µg/l, PCE at a maximum concentration of 0.06 µg/l, 1,1,1-TCA at a maximum concentration of 4 µg/l, and TCE at a maximum concentration of 0.1 µg/l.

## 2.5 TRANSPORT OF CHEMICALS

The following section addresses the movement of chemicals in groundwater and subsurface soil into other media. Modeling was conducted to determine the migration of VOCs from groundwater and subsurface soil into air, and the migration of VOCs from subsurface soil into groundwater. This information will be used to determine potential exposure pathways for the health risk assessment (Section 3.0).

### 2.5.1 TRANSPORT OF CHEMICALS FROM SOIL TO GROUNDWATER

To assess the potential impact of VOCs migrating from the onsite soil into groundwater, Levine-Fricke performed subsurface transport modeling for the Sola Optical site. This section summarizes the methodology and results of that modeling. The information contained in this section is based primarily on a draft technical memorandum from Levine-Fricke (1991), Results of Subsurface Transport Modeling, Sola Optical USA Inc. Site (See Attachment I).

The modeling was performed by Levine-Fricke in two steps. The first step simulated the mass loading of contaminants from the soil into the groundwater using the program VLEACH (developed by CH2M HILL and summarized in Attachment II); the second step simulated groundwater flow and transport using a simple mixing cell model. Two VOCs were modeled: 1,1-DCA and 1,1-DCE. These two chemicals were chosen because it was believed they presented the greatest potential risk to human health at the Sola Optical site (Levine-Fricke, 1991).

The one-dimensional finite difference computer model, VLEACH, was used to simulate the transport of chemicals from vadose zone soils to the water table. VLEACH simulates movement of contaminants with the soil water (steady state advective soil water transport) and movement of contaminants in the soil-gas by diffusion (diffusive soil vapor transport). In addition to advection and diffusion, the model accounts for partitioning between adsorbed, dissolved, and vapor phases. Soil properties used in the model were derived by Levine-Fricke from published data and results of previous field investigations.

The initial distribution of VOC contamination in the soil was determined by Levine-Fricke based on either previous site soil sampling results or by calculations using soil-gas sampling results. VOC concentrations were assumed to be zero in surficial soils, and to increase linearly to the depth at which VOCs were first detected in soil samples. Concentrations in the soil were then linearly interpolated between the first depth at which VOCs were detected and the second depth at which they were detected. This process continued to the deepest sample whose concentration was assigned to all the soil between that deepest sample and the water table.

A simple mixing cell model, written by Levine-Fricke (1991), was used to estimate the effect of 1,1-DCA and 1,1-DCE entering into the groundwater at the Sola Optical site.

The model assumed that all mass entering into the groundwater was immediately mixed with the groundwater. A portion of the contaminated groundwater flowed offsite every year and was replaced with fresh water flowing into the site. Levine-Fricke (1991) assumed that the shallow groundwater bearing zone beneath the site was 24 meters wide by 12 meters long by 11 meters deep. Total porosity was set at 0.4 and the groundwater flow rate was estimated to be 595 cubic meters per year (Levine-Fricke, 1991).

Results from this model indicated that the additional 1,1-DCA leaching into the groundwater would result in a concentration of 0.41  $\mu\text{g/l}$  after seven years. The additional 1,1-DCE added to the groundwater resulted in a maximum concentration of 0.70  $\mu\text{g/l}$  after 6 years.

## **2.5.2 TRANSPORT OF CHEMICALS FROM GROUNDWATER AND SOIL TO AIR**

Concentrations of VOCs that may diffuse into a building or house built on the Sola Optical site have been estimated based on existing soil, soil-gas, and groundwater concentration data. Estimation of this flux from soil into a building was calculated using existing data in conjunction with Fick's first law of diffusion. The concentration of VOCs inside a house was then calculated based on these flux estimates.

Based on Tables 2-3, 2-6, and Figure 2-6, a total of twelve chemicals were detected during the 1990 sampling of site groundwater, soil-gas, and soil. These twelve chemicals are acetone, butanone, 1,1-DCA, 1,2-DCA, 1,1-DCE, Freon 113, 4-methyl-2-pentanone, PCE, toluene, 1,1,1-TCA, 1,1,2-TCA, and TCE. As a screening estimate of air concentrations in a home, the maximum chemical concentration found in each media has been used in the modeling.

Potential gas concentrations within an onsite building were estimated by incorporating soil-gas concentrations (calculated or measured) into equations that calculate the flux through a building foundation. Soil-gas concentrations were obtained from either the soil-gas sampling results (Figure 2-6), or were estimated from groundwater monitoring (Table 2-3) and soil sampling (Table 2-7) results. Methodology for converting groundwater and soil concentrations to soil-gas concentrations are described below.

### **Estimating Soil-Gas Concentrations from Groundwater Samples**

For contaminants detected in groundwater samples, soil-gas concentrations were estimated using Henry's law constant,  $H$  ( $\text{atm} \cdot \text{m}^3/\text{mole}$ ). The Henry's law constant is a measure of the chemical partitioning between air and water at equilibrium. The unitless Henry's law constant,  $H^1$ , is equal to  $H$  at standard temperature and pressure and is empirically related to the ratio of the concentration in the gas phase (e.g., soil-gas),  $C_{\text{sg}}$ , over the concentration in the liquid phase (e.g., soil water),  $C_{\text{sl}}$ , at an interface.

$$H^1 = H/RT = C_{sg}/C_{sl} \quad (1)$$

where R is the Universal gas constant, and T is temperature. The higher the constant, the more likely a chemical is to volatilize than remain in water. The Henry's law constants used in this assessment are listed on Table 2-8.

### Estimating Soil-Gas Concentrations from Soil Samples

Concentrations of contaminants in soil samples were used to estimate soil-gas concentration if the contaminant was not detected in groundwater or soil-gas samples (e.g., butanone, 1,2-DCA, 4-methyl-2-pentanone, and 1,1,2-TCA). To estimate soil-gas concentrations from the soil sampling results, a two-step process was used. First, soil concentrations were converted to soil water concentrations; second, soil water concentrations were converted to soil-gas concentrations.

To convert the soil concentration of a contaminant to the soil water concentration, the Freundlich constant,  $K_f$ , was used. The Freundlich constant is a measure of the chemical partitioning between soil and soil water.

$$K_f = \frac{\text{Amount Adsorbed to Soil}}{\text{Soil Water Concentration}} \quad (2)$$

This chemical partitioning is affected by the organic content of the soil, therefore  $K_f$  can also be defined as the product of the organic carbon partition coefficient ( $K_{oc}$ ) and the fraction of organic carbon in the soil ( $f_{oc}$ ). Knowing the  $K_{oc}$  and the  $f_{oc}$  of the soil, and the chemical concentration in the soil, the concentration in the soil water can be determined.

$$K_f = (K_{oc})(f_{oc}) \quad (3a)$$

$$\text{therefore, } \frac{\text{Amount Adsorbed to Soil}}{K_{oc} \times f_{oc}} = \text{Soil Water Concentration} \quad (3b)$$

$K_{oc}$  values used in the calculations are shown on Table 2-8. (A  $K_{oc}$  value was not available for 4-methyl-2-pentanone, and therefore, no soil-gas concentrations have been

calculated for this chemical). The fraction of organic carbon ( $f_{oc}$ ) for soil at the Sola Optical site is assumed to be 0.02 (Levine-Fricke, 1991). Henry's law constant was then applied to the estimated soil water concentration to estimate the soil-gas concentration.

### Estimate of Contaminant Flux

In order to calculate the soil-gas concentration at ground level, and the contaminant flux,  $J$ , into a home or building, Fick's first law was applied to the soil-gas concentrations. First, the soil gas concentration at ground level was calculated, based on contaminant flux from depth,  $L$ .

$$J = D \frac{(C_2 - C_1)}{L} \quad (4)$$

where:

- $D$  = the rate of movement of chemicals in the vadose zone (diffusivity);
- $C_2$  = the chemical concentration in the soil-gas at depth  $L$ ;
- $C_1$  = the chemical concentration in the soil-gas at the surface; and
- $L$  = the depth at which the soil-gas concentration,  $C_2$ , is known.

Chemical movement in the soil-gas, vadose zone diffusivities ( $D$ ), were approximated by using the Millington Quirk (1961) formula:

$$D = D_0 \left( \frac{a^{10/3}}{\Phi^2} \right) \quad (5)$$

where:

- $D_0$  = the diffusion into the air (e.g., of a home);
- $a$  = the air filled porosity; and
- $\Phi$  = the total porosity.

Soil-gas and air diffusivity values were calculated using correlations from Fuller (Reid, et al.). According to Levine-Fricke (1991), the total porosity is 0.5, and the air filled porosity is 0.2 for soils at the site. Soils at the site consist mainly of black, damp to moist clays (Levine-Fricke, 1990).

Because the concentration in the house,  $C_h$ , is not known, Fick's first law must be solved iteratively to determine the steady state contaminant fluxes from the ground



surface into a building. Estimates of air concentrations in a house were calculated from these fluxes using the following equation:

$$C_h = \frac{(J)(A)(\%)(R)}{V} \quad (6)$$

where:

$C_h$	=	the concentration of the contaminant in the air in the house;
$J$	=	the flux of contaminant at the ground surface;
$A$	=	the area of the house foundation;
$\%$	=	the proportion of vapors that enter the house;
$R$	=	the residence time of air in the house; and
$V$	=	the volume of air in the house.

Residence time of air in a typical house is 2 hours and a typical volume is 400 cubic meters (McKone, 1987). The area of the house was assumed to be 1,300 square feet, and the proportion of volatiles that enter the house was assumed to be 0.005 (0.5 percent) (Personal Communication, 1991b). This was based on the assumption that approximately 0.5 percent of the foundation of the house was cracked and therefore accessible to the entering soil vapor. This would indirectly translate into 0.5 percent of the VOCs entering the house assuming no additional limiting factors to the entrance of the soil vapors into the house other than the foundation barrier.

The results of these calculations for each of the twelve contaminants are shown on Table 2-9.

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**Table 2-1**  
**Depth of Levine-Fricke Groundwater Monitoring Wells**  
**LF-1 through LF-28**

<b>Well Number</b>	<b>Screened Interval (feet below grade)</b>	<b>Sediment Depth Interval</b>
LF-1	--	--
LF-2	20 - 29	Shallow
LF-3	44 - 50	Intermediate
LF-4	35 - 40	Intermediate
LF-5	24 - 33	Shallow
LF-6	39 - 43	Intermediate
LF-7	25 - 35	Shallow
LF-8	25 - 34	Shallow
LF-9	30 - 38	Intermediate
LF-10	29 - 44	Intermediate
LF-11	4 - 9	Shallow
LF-12	212 - 233	Deepest
LF-13	151 - 161	Deeper
LF-14	79 - 89	Deep
LF-15	205 - 215	Deepest
LF-16	163 - 173	Deeper
LF-17	68 - 78	Deep
LF-18	92 - 102	Deep
LF-19	36 - 47	Intermediate
LF-20	14 - 24	Shallow
LF-21	40 - 50	Intermediate
LF-22	39 - 49	Intermediate
LF-23	45 - 55	Intermediate
LF-24	84 - 94	Deep
LF-25	18 - 28	Shallow
LF-26	38 - 48	Intermediate
LF-27	220 - 240	Deepest
LF-28	14 - 24	Shallow

Source: Levine-Fricke, 1990. Depths were not given for LF-1.

**Table 2-2**  
**Chemicals Detected in Wells LF-1 through LF-28**  
**during Annual and Semiannual 1990 Groundwater Sampling**

<b>Chemical</b>	<b>No. Detected/No. Sampled<sup>a</sup></b>
1,1,1-Trichloroethane	22/74
1,1,2,2-Tetrachloroethane	0/74
1,1,2-Trichloroethane	0/74
1,1-Dichloroethane	10/74
1,1-Dichloroethene	26/74
1,2-Dichlorobenzene	0/55
1,2-Dichloroethane	0/74
1,2-Dichloroethene, total	0/73
1,2-Dichloropropane	0/74
1,3-Dichlorobenzene	0/55
1,4-Dichlorobenzene	0/55
2-Butanone	0/19
2-Chloroethyl Vinyl Ether	0/70
2-Hexanone	0/19
4-Methyl-2-pentanone	0/19
Acetone	0/19
Benzene	0/19
Bromodichloromethane	0/74
Bromoform	0/74
Bromomethane	0/74
Carbon Disulfide	0/19
Carbon Tetrachloride	0/74
Chlorobenzene	0/74
Chloroethane	0/74
Continued	

**Table 2-2**  
**Chemicals Detected in Wells LF-1 through LF-28**  
**during Annual and Semiannual 1990 Groundwater Sampling**

Chemical	No. Detected/No. Sampled <sup>a</sup>
Chloroform	0/74
Chloromethane	0/74
Dibromochloromethane	0/74
Dichlorodifluoromethane	0/55
Ethylbenzene	0/19
Freon 113	4/55
Methylene Chloride	0/74
Styrene	0/19
Tetrachloroethene	0/74
Toluene	3/19
Trichloroethene	0/74
Trichlorofluoromethane	0/55
Vinyl Acetate	0/19
Vinyl Chloride	0/74
Xylenes, total	0/19
cis-1,3-Dichloropropene	0/74
trans-1,2-Dichloroethene	0/1
trans-1,3-Dichloropropene	0/74

<sup>a</sup>Total number of samples includes duplicates and splits.

Table 2-3 Groundwater Quality Data--LF-1 through LF-28 <sup>a</sup> (Concentrations Expressed in mg/l)								
Well No.	Lab	Analysis	Date Sampled	Notes	1,1-DCE	1,1-DCA	TCA	Freon 113
LF-2	MED	EPA 8010	05/03/90		0.022	<0.0005	0.012	<0.0005
	MED	EPA 8010	08/31/90		0.021	0.004	0.005	<0.0005
LF-3	MED	EPA 8010	04/26/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	08/31/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-4	MED	EPA 8010	04/26/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	08/31/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-5	MED	EPA 8010	05/01/90		0.002	<0.0005	0.0007	<0.0005
	MED	EPA 8010	09/10/90		0.0006	<0.0005	<0.0005	<0.0005
LF-6	MED	EPA 8010	05/01/90		0.002	<0.0005	0.0007	<0.0005
	MED	EPA 8010	09/10/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-7	MED	EPA 601	05/04/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 601	08/30/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-8	MED	EPA 601	05/01/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 601	08/30/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-9	MED	EPA 8010	05/03/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	09/10/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	duplicate		<0.0005	<0.0005	<0.0005	<0.0005
LF-10	MED	EPA 601	04/25/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-12	MED	EPA 8010	04/27/90		0.0007	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	09/11/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-13	MED	EPA 8010	05/02/90		0.022	<0.0005	0.002	0.002
	EPA	EPA 8240	split		0.015	0.001	0.008	NA
	MED	EPA 8010	09/11/90		0.007	<0.0005	0.003	<0.0005
LF-14	MED	EPA 8010	04/02/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	08/30/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-15	MED	EPA 8010	04/24/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	08/29/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-16	MED	EPA 8010	04/25/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	08/28/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-17	MED	EPA 8010	05/02/90		0.020	0.0009	0.01	0.0006
	EPA	EPA 8240	split		0.018	0.002	0.009	NA
	MED	EPA 8010	08/29/90	b	0.019	0.001	0.009	<0.0005
	EPA	EPA 8240	split		0.014	0.002	0.008	NA
LF-18	MED	EPA 8010	04/25/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	08/30/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-19	MED	EPA 8010	04/24/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-20	MED	EPA 8010	04/24/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-21	MED	EPA 8240	04/24/90		<0.005	<0.005	<0.005	NA
	MED	EPA 8240	duplicate		<0.005	<0.005	<0.005	NA
	MED	EPA 8010	05/02/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	duplicate		<0.0005	<0.0005	<0.0005	<0.0005
	EPA	EPA 8240	split	c	<0.001	<0.001	<0.001	NA
	MED	EPA 8010	08/29/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-22	MED	EPA 8240	04/24/90		0.006	<0.005	<0.005	NA
	MED	EPA 8010	04/30/90		0.012	<0.0005	0.004	<0.0005
	MED	EPA 8010	08/30/90		0.020	0.0006	0.007	<0.0005
LF-23	MED	EPA 8240	04/23/90		<0.005	<0.005	<0.005	NA
	MED	EPA 8010	04/30/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	08/30/90		<0.0005	<0.0005	<0.0005	<0.0005
Continued								

Table 2-3 Groundwater Quality Data--LF-1 through LF-28 <sup>a</sup> (Concentrations Expressed in mg/l)								
Well No.	Lab	Analysis	Date Sampled	Notes	1,1-DCE	1,1-DCA	TCA	Freon 113
LF-24	MED	EPA 8240	04/19/90		<0.005	<0.005	<0.005	NA
	MED	EPA 8240	duplicate		<0.005	<0.005	<0.005	NA
	MED	EPA 8010	05/02/90		<0.0005	<0.0005	<0.0005	<0.0005
	EPA	EPA 8240	split		<0.001	<0.001	<0.001	NA
	MED	EPA 8010	08/30/90		<0.0005	<0.0005	<0.0005	<0.0005
LF-25	MED	EPA 8240	04/23/90		0.005	<0.005	<0.005	NA
	MED	EPA 8010	04/30/90		0.007	<0.0005	0.004	0.001
	MED	EPA 8010	08/29/90		0.004	<0.0005	0.003	<0.0005
	MED	EPA 8010	duplicate		0.004	<0.0005	0.002	<0.0005
	EPA	EPA 8240	split		0.003	0.0007	0.003	NA
LF-26	MED	EPA 8240	04/23/90		<0.0005	<0.0005	<0.0005	NA
	MED	EPA 8010	04/30/90		<0.0005	0.005	0.004	0.004
	MED	EPA 8010	08/29/90		0.002	<0.0005	0.0008	<0.0005
	MED	EPA 8010	duplicate		0.002	<0.0005	0.001	<0.0005
	EPA	EPA 8240	split		0.002	0.0002	0.002	NA
LF-27	MED	EPA 8240	04/24/90		<0.005	<0.005	<0.005	NA
	MED	EPA 8010	05/03/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	duplicate		<0.0005	<0.0005	<0.0005	<0.0005
	EPA	EPA 8240	split	d	<0.001	<0.001	<0.001	NA
	MED	EPA 8010	08/28/90		<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	duplicate		<0.0005	<0.0005	<0.0005	<0.0005
LF-28	MED	EPA 8240	04/20/90		<0.005	<0.005	<0.005	NA
	MED	EPA 8010	05/01/90		0.0006	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	08/29/90		<0.0005	<0.0005	<0.0005	<0.0005
	EPA	EPA 8240	split		0.0009	<0.001	0.0008	NA
<sup>a</sup> Source: Levine-Fricke, 1990. <sup>b</sup> Toluene detected at 0.003 mg/l. <sup>c</sup> Toluene detected at 0.003 mg/l. <sup>d</sup> Toluene detected at 0.017 mg/l.  Notes: NA = Not Analyzed  Analytical Laboratories: MED = Med-Tox Associates, Inc., Pleasant Hill, California EPA = U.S. Environmental Protection Agency. Split samples collected by EPA and analyzed by EPA contract laboratory.								

**Table 2-4**  
**Groundwater Quality Data--W.Wells<sup>a</sup>**  
**(Concentrations Expressed in mg/l)**

Well No.	Lab	Analysis	Date Sampled	Notes	1,1-DCE	1,1-DCA	1,2-DCA	TCA	TCE	Freon 113
W-12	MED	EPA 8010	05/04/90		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
W-13	MED	EPA 8010	04/26/90		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	MED	EPA 8010	08/31/90		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
W-14	MED	EPA 8010	04/26/90	b	1.2	0.084	0.002	0.220	0.003	0.007
	MED	EPA 8010	duplicate	c	1.2	0.081	0.002	0.200	0.002	0.006
	MED	EPA 8010	09/10/90	d	1.4	0.110	0.002	0.200	0.002	0.005
W-15	MED	EPA 8010	05/01/90		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
W-21	MED	EPA 8010	04/27/90		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
W-24	MED	EPA 8010	05/03/90		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
W-26		EPA 8010	04/20/90		0.01	0.009	<0.0005	0.003	<0.0005	<0.0005
W-27	MED	EPA 8010	05/02/90		0.004	<0.0005	0.001	<0.0005	<0.0005	<0.0005
W-28	MED	EPA 8010	05/02/90	e	0.17	0.280	0.001	0.032	<0.0005	0.001
	MED	EPA 8010	09/11/90	f	0.074	0.170	<0.0005	0.012	<0.0005	<0.0005
W-30	MED	EPA 8010	05/02/90		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
W-33	MED	EPA 8010	04/20/90		0.003	<0.0005	<0.0005	0.003	<0.0005	<0.0005
	MED	EPA 8010	09/11/90		0.003	<0.0005	<0.0005	0.0009	<0.0005	<0.0005

<sup>a</sup>Source: Levine-Fricke, 1990.

<sup>b</sup>Chloroform, 1,1,2-TCA, PCE, and Freon 11 detected at 0.002, 0.003, and 0.004 mg/l, respectively.

<sup>c</sup>Chloroform, 1,1,2-TCA, PCE, and Freon 11 detected at 0.001, 0.003, 0.002, and 0.003 mg/l, respectively.

<sup>d</sup>Chloroform detected at 0.0009 mg/l, PCE detected at 0.001 mg/l, 1,1,2-TCA and Freon 11 detected at 0.002 mg/l.

<sup>e</sup>Freon 11 detected at 0.009 mg/l.

<sup>f</sup>Freon 11 detected at 0.0007 mg/l.

Notes:

NR = Not Reported

Analytical Laboratories:

MED = Med-Tox Associates, Inc., Pleasant Hill, California.



**Table 2-5**  
**Federal and State Maximum Contaminant Levels for Drinking Water**

Chemical	Maximum Contaminant Levels (MCLs) (mg/l)	
	Federal <sup>a</sup>	State <sup>b</sup>
1,1-DCA	--	0.005
1,1-DCE	0.007	0.006
Freon 113	--	1.2
Toluene	2.0	--
1,1,1-TCA	0.2	0.2

<sup>a</sup>Safe Drinking Water Act (40 CFR 141). Toluene MCL proposed May 22, 1989 (Federal Register, Vol. 54, No. 97).

<sup>b</sup>Source: California Department of Health Services, 1990.

Table 2-6 Groundwater Quality Data--Station 5 Well (Concentrations Expressed in mg/l)										
Well No.	Lab	Analysis	Date Sampled	Notes	1,1-DCE	1,1-DCA	1,2-DCA	TCA	TCE	Freon 113
Station 5	M-T	EPA 601	11/20/86		<0.0001	<0.0001	<0.0001	0.0009	<0.0001	NR
	CAL	EPA 601	12/10/86		0.0005	<0.0005	<0.0005	0.0005	<0.0005	<0.0005
	CAL	EPA 601	12/10/86		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	M-T	EPA 601	12/12/86		0.0009	0.0009	<0.0001	0.0032	<0.0001	NR
	M-T	EPA 601	12/30/86		0.0004	<0.0001	<0.0001	0.0007	<0.0001	NR
	CAL	EPA 601	02/05/87		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	B&C	EPA 601	02/05/87		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	CAL	EPA 601	02/26/87		0.0008	<0.0005	<0.001	<0.0005	<0.001	<0.001
	CAL	EPA 601	02/26/87		<0.0005	<0.0005	<0.001	0.0005	<0.001	<0.001
	M-T	EPA 601	03/27/87	b	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	NR
	CAL	EPA 601	04/21/87	c	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	<0.001
	M-T	EPA 601	05/22/87	b	<0.0002	<0.0005	<0.0005	<0.0005	<0.0005	NR
	M-T	EPA 601	12/03/87		0.0013	0.0006	<0.0005	0.0012	<0.0005	NR
	M-T	EPA 601	12/21/87		0.0012	0.0007	<0.0005	0.0014	<0.0005	NR
	MED	EPA 601	12/30/87		0.002	<0.0005	<0.0005	0.002	<0.0005	NR
	MED	EPA 601	01/13/88		0.001	<0.0005	<0.0005	0.001	<0.0005	NR
	MED	EPA 601	05/26/88		0.002	<0.0005	<0.0005	0.0009	<0.0005	<0.0005
	MED	EPA 601	duplicate		0.002	<0.0005	<0.0005	0.0009	<0.0005	<0.0005
NR = Not reported										
<sup>a</sup> Source: Levine-Fricke 1990.										
<sup>b</sup> Samples were collected by Multi-Tech personnel for the City of Petaluma.										
<sup>c</sup> Chloroform detected at 0.002 mg/l, bromodichloromethane detected at 0.0025 mg/l, and dibromochloromethane detected at 0.0022 mg/l.										
Analytical Laboratories:										
M-T = Multi-Tech Laboratories, Inc., Santa Rosa, California										
CAL = California Analytical Laboratories, Inc., Sacramento, California										
B&C = Brown and Caldwell Laboratories, Emeryville, California										
MED = Med-Tox Associates, Inc., Pleasant Hill, California										

**Table 2-7**  
**Summary of Soil Chemical Analyses Data<sup>a</sup>**  
 (Concentrations Expressed in mg/kg)

Sample No.	Depth (ft)	1,1-DCA		1,1,1-TCA		1,1,2-TCA		1,1-DCE		PCE		TCE		1,2-DCA		Toluene	Acetone	2-Butanone	4-Methyl-2-Pentanone
		8240 <sup>b</sup>	8010 <sup>c</sup>	8240 <sup>b</sup>	8010 <sup>c</sup>	8240 <sup>b</sup>	8010 <sup>c</sup>	8240 <sup>b</sup>	8010 <sup>c</sup>	8240 <sup>b</sup>	8010 <sup>c</sup>	8240 <sup>b</sup>	8010 <sup>c</sup>	8240 <sup>b</sup>	8010 <sup>c</sup>	8240 <sup>b</sup>	8240 <sup>b</sup>	8240 <sup>b</sup>	8240 <sup>b</sup>
SB-1	3-3.5	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	0.031	<0.1	<0.1	<0.5
	7-7.5	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	0.11	<0.1	<0.1	<0.5
SB-2	3-3.5	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	0.061	<0.1	<0.1	<0.05
	7-7.5	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	0.14	4.6	0.15	0.27
SB-3	3-3.5	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	0.07	<0.1	<0.1	<0.05
	8.5-9	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	0.19	<0.1	<0.1	<0.05
EPA Split	9-9.5	<0.006	NA	NR	NA	NR	NA	NR	NA	NR	NA	NR	NA	<0.006	NA	0.016	NR	NR	NR
SB-4	3-3.5	0.016	0.003	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	0.24	0.11	<0.1	<0.05
	9-9.5	0.051	0.029	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	0.2	<0.1	<0.1	<0.05
SB-5	3-3.5	0.02	0.012	0.008	0.012	0.006	0.005	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	0.042	<0.1	<0.1	<0.05
	9-9.5	0.16	0.19	0.018	0.019	0.012	0.019	0.034	0.013	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	0.038	<0.1	<0.1	<0.05
SB-6	3-3.5	0.014	<0.001	0.019	0.026	0.034	0.035	0.005	<0.001	0.011	0.015	0.007	0.009	<0.005	<0.001	0.007	<0.1	<0.1	<0.05
	9-9.5	0.016	0.007	<0.005	<0.001	0.006	0.003	<0.005	<0.001	<0.005	<0.001	<0.005	<0.001	<0.005	0.003	0.14	<0.1	<0.1	<0.05
EPA Split	8.5-9	0.022	NA	NR	NA	0.007	NA	NR	NA	NR	NA	NR	NA	0.006J	NA	0.12	NR	NR	NR

<sup>a</sup>Source: Levine-Fricke, 1990.

<sup>b</sup>EPA Method 8240

<sup>c</sup>EPA Method 8010

NR = Not Reported

NA = Not Analyzed

EPA Split = "Split" sample collected by the U.S. Environmental Protection Agency and analyzed by a U.S. EPA contract laboratory

J = Results are estimated; data are valid for limited purposes.

Results are qualitatively acceptable.

**Table 2-8**  
**Physical/Chemical Constants**

<b>Chemical</b>	<b>Henry's Law Constant (atm-m<sup>3</sup>/mol)</b>	<b>Koc (ml/g)</b>
Acetone	(a)	(a)
2-Butanone	$5.59 \times 10^{-5}$	4.5
1,1-Dichloroethane	$5.62 \times 10^{-3}$	(b)
1,2-Dichloroethane	$9.79 \times 10^{-4}$	14
1,1-Dichloroethene	$2.61 \times 10^{-2}$	(b)
Freon 113	(a)	(a)
Tetrachloroethene (PCE)	(a)	(a)
Toluene	$6.64 \times 10^{-3}$	(b)
1,1,1-Trichloroethane (1,1,1-TCA)	$1.72 \times 10^{-2}$	(b)
1,1,2-Trichloroethane (1,1,2-TCA)	$9.13 \times 10^{-4}$	56
Trichloroethene (TCE)	(a)	(a)

Note: Source is U.S. EPA 1986 and 1989.

(a) Soil-gas measurements were available for this chemical; therefore, calculation of soil-gas concentrations was not necessary.

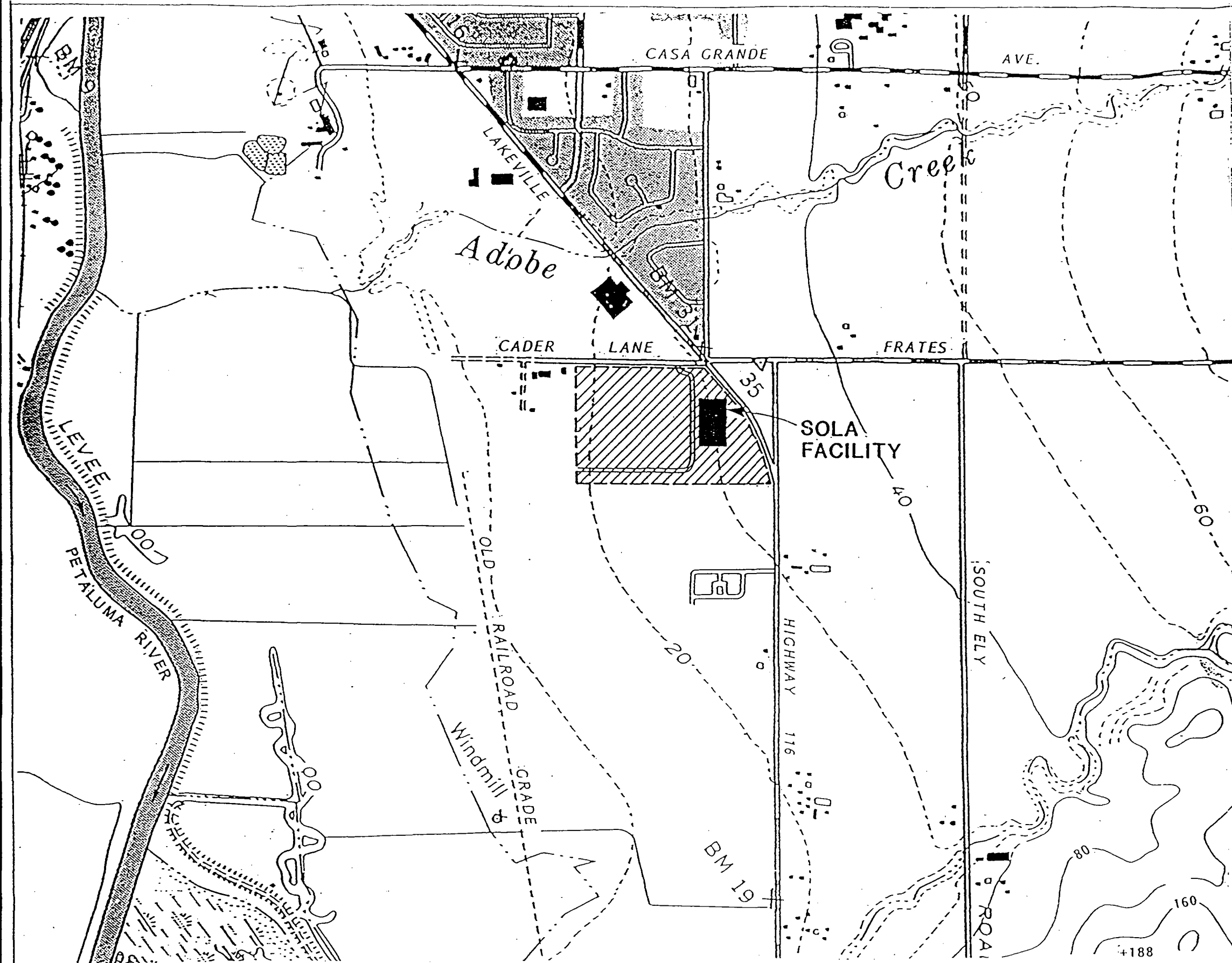
(b) Soil-gas concentrations were estimated for this chemical from groundwater concentrations.

**Table 2-9**  
**Estimated VOC Concentration Inside a House**

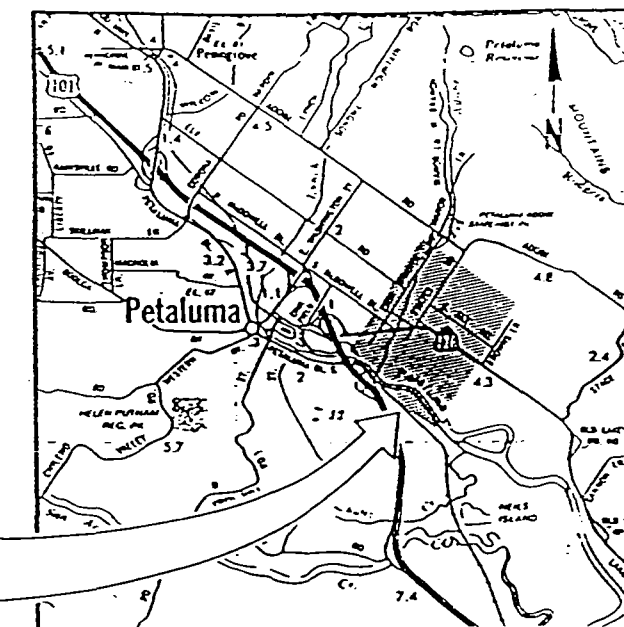
Contaminant	Soil-gas Concentration ( $\mu\text{g/l}$ )	$D_0$ ( $\text{ft}^2/\text{hr}$ )	$D$ ( $\text{ft}^2/\text{hr}$ )	Depth (feet)	Flux ( $\mu\text{g}/\text{ft}^2/\text{hr}$ )	Concentration in house ( $\mu\text{g/l}$ )
Acetone (2' soil-gas)	0.10	0.46	0.0087	2	1.2376E-02	4.0221E-07
Butanone (7' soil sample)	1.90	0.30	0.0056	7	4.3153E-02	1.4025E-06
1,1-DCA (2' soil-gas)	0.60	0.33	0.0063	2	5.3270E-02	1.7313E-06
1,1-DCA (7' soil-gas)	12.00	0.33	0.0063	7	3.0440E-01	9.8930E-06
1,1-DCA (groundwater)	1.17	0.33	0.0063	8	2.5969E-02	8.4399E-07
1,2-DCA (8.5' soil sample)	0.87	0.33	0.0063	8.5	1.8237E-02	5.9271E-07
1,1-DCE (3' soil-gas)	0.60	0.34	0.0065	3	3.6589E-02	1.1892E-06
1,1-DCE (7' soil-gas)	68.00	0.34	0.0065	7	1.7772E+00	5.7759E-05
1,1-DCE (groundwater)	23.90	0.34	0.0065	10	4.3724E-01	1.4210E-05
Freon 113 (3' soil-gas)	0.40	0.28	0.0053	3	2.0088E-02	6.5287E-07
PCE (2' soil-gas)	0.003	0.27	0.0051	2	2.1792E-04	7.0825E-09
PCE (7' soil-gas)	0.06	0.27	0.0051	7	1.2453E-03	4.0471E-08
Toluene (groundwater)	0.74	0.29	0.0055	8	1.4493E-02	4.7101E-07
1,1,1-TCA (2' soil-gas)	0.40	0.29	0.0055	2	3.1209E-02	1.0143E-06
1,1,1-TCA (7' soil-gas)	4.00	0.29	0.0055	7	8.9167E-02	2.8979E-06
1,1,1-TCA (groundwater)	8.85	0.29	0.0055	10	1.3810E-01	4.4882E-06
1,1,2-TCA (3' soil sample)	1.48	0.29	0.0056	3	7.8043E-02	2.5364E-06
TCE (2' soil-gas)	0.02	0.30	0.0057	2	1.6142E-03	5.2463E-08
TCE (7' soil-gas)	0.10	0.30	0.0057	7	2.3061E-03	7.4947E-08

**ASSUMPTIONS:**

- 1) Millington-Quirk model of diffusion ( $\theta = 0.5$ ,  $\phi = 0.3$ )
- 2) Ficks Law
- 3) Area of House - 1,300  $\text{ft}^2$
- 4) % Infiltration of gas into house = 0.005 (.5%)
- 5) Residence time of air in house = 2 hr
- 6) Volume of air in house 14,124  $\text{ft}^3$
- 7) Fraction of organic carbon ( $f_{oc}$ ) = 0.02



SOURCE: U.S. Geological Survey 7.5 minute  
Petaluma River quadrangle,  
photo revised 1980.

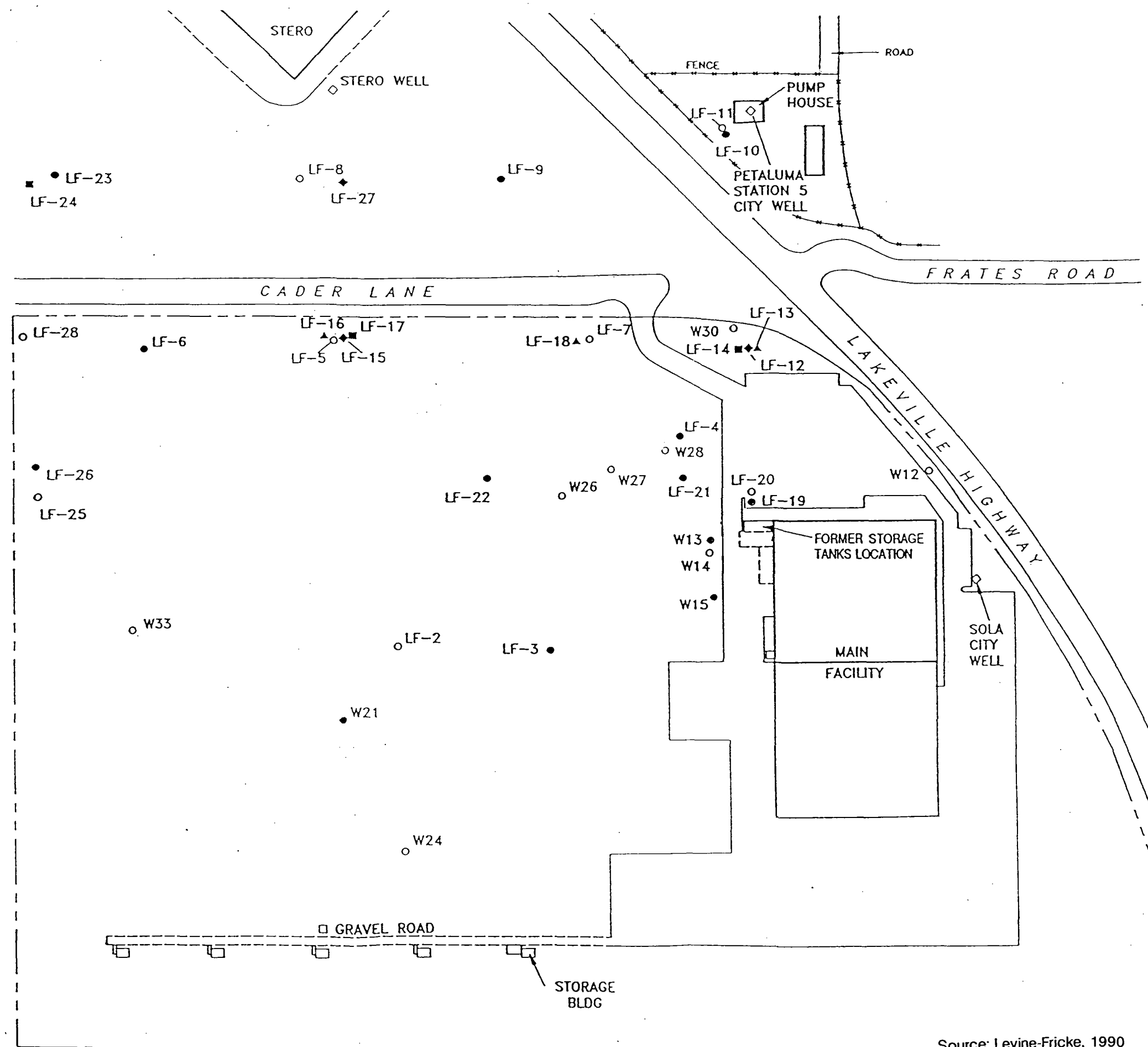


LOCATION MAP

0 1000 2000 feet

Source: Levine-Fricke, 1990

FIGURE 2-1  
FACILITY LOCATION MAP



# EXPLANATION

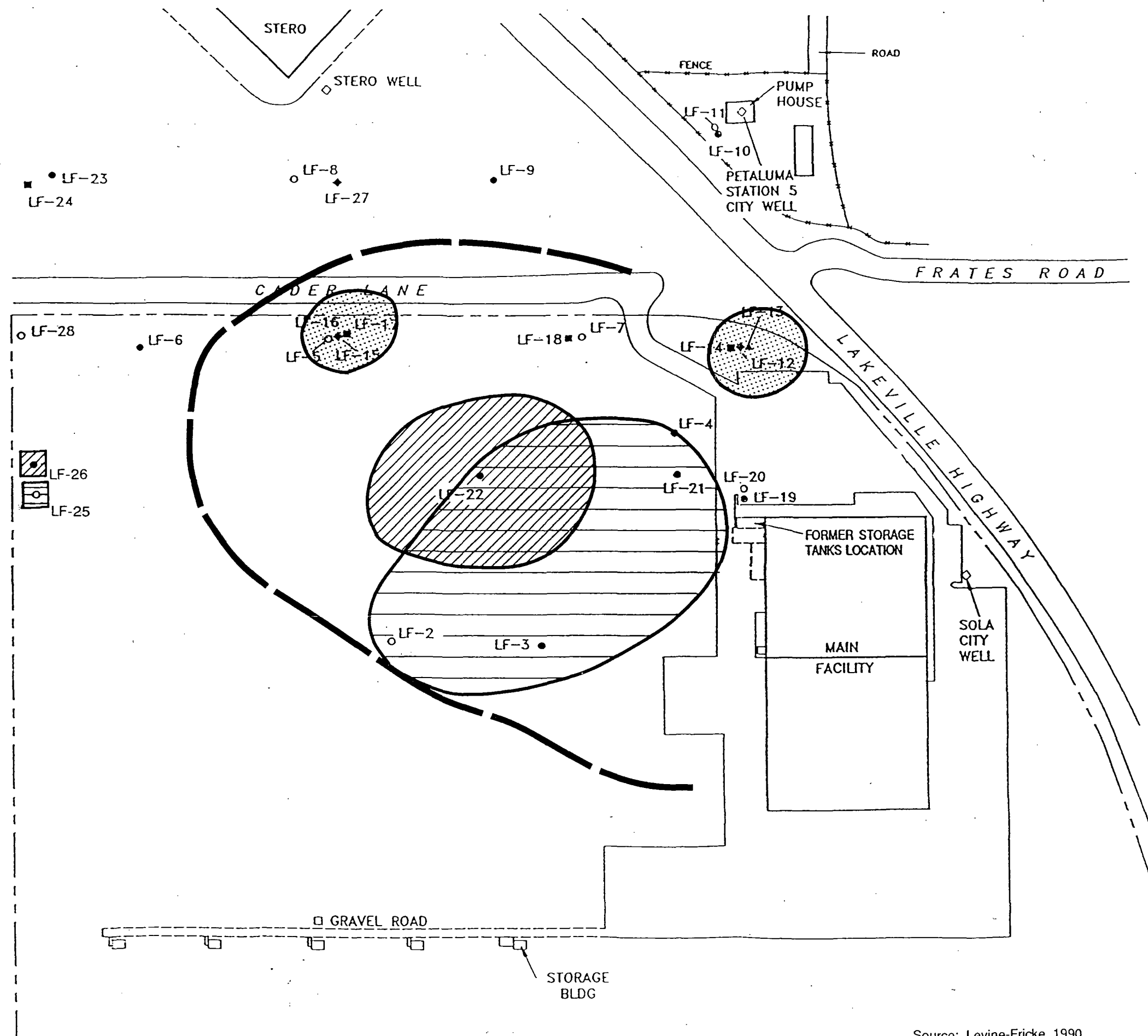
- Shallow (up to approx. 30 feet) monitoring well
- Intermediate (up to approx. 60 feet) monitoring well
- Deep (up to approx. 100 feet) monitoring well
- ▲ Deeper (up to approx. 200 feet) monitoring well
- ◆ Deepest (approx. >200 feet) monitoring well

—\*—\*—\*— Fencing

0 150 FEET

FIGURE 2-3  
LOCATION OF MONITORING WELLS  
SAMPLED IN 1990

Source: Levine-Fricke, 1990



# EXPLANATION

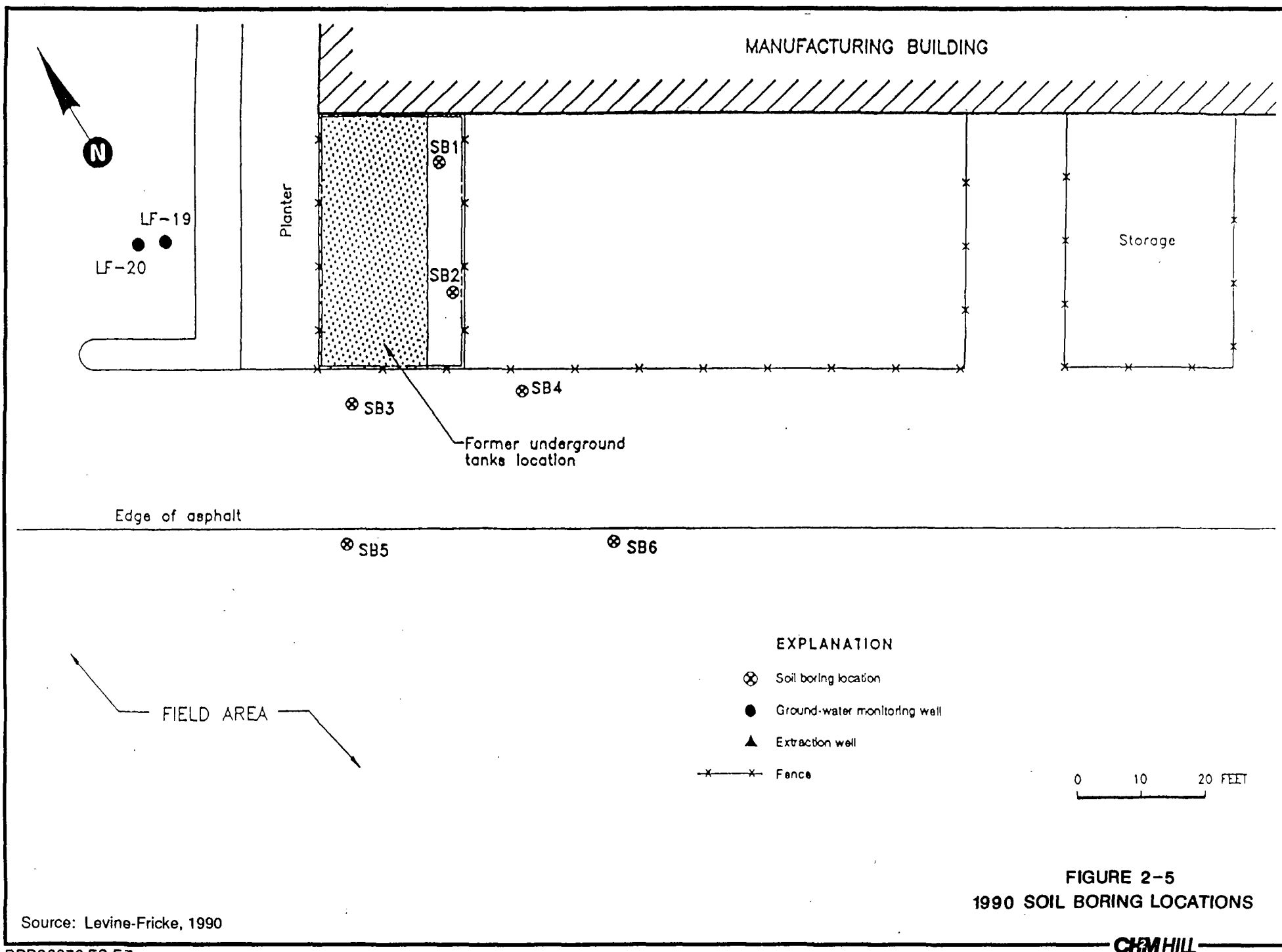
- Shallow (up to approx. 30 feet) monitoring well
- Intermediate (up to approx. 60 feet) monitoring well
- Deep (up to approx. 100 feet) monitoring well
- ▲ Deeper (up to approx. 200 feet) monitoring well
- ◆ Deepest (approx. >200 feet) monitoring well
- Estimated limit of shallow-depth groundwater capture
- ▨ Shallow-depth groundwater greater than MCL's
- ▤ Intermediate-depth groundwater greater than MCL's
- ▧ Deep and deeper-depth groundwater greater than MCL's
- Fencing

0 150 FEET

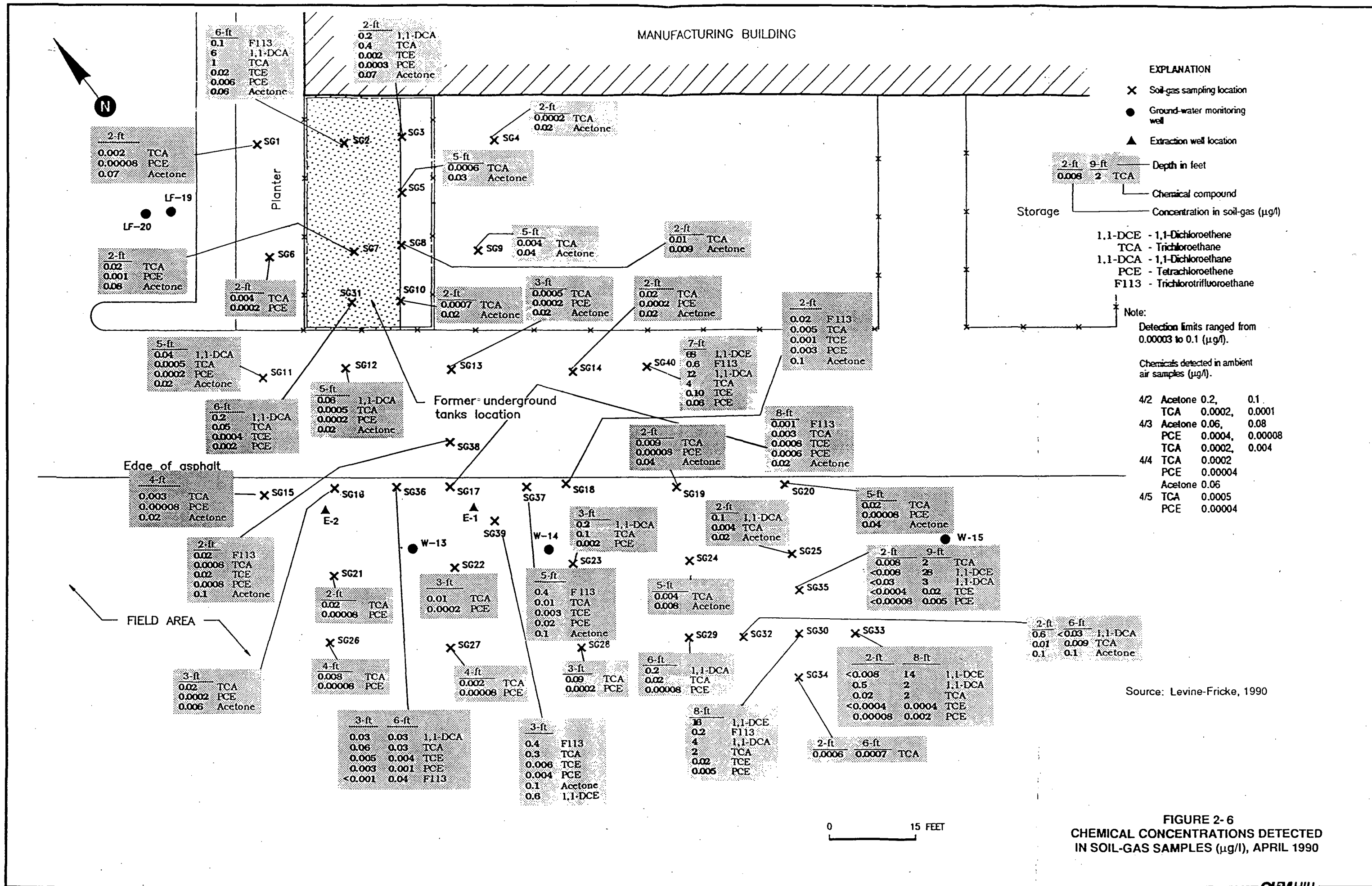
FIGURE 2-4  
VOC CONCENTRATIONS GREATER THAN  
MCL's IN SHALLOW, INTERMEDIATE,  
DEEP, AND DEEPER-DEPTH GROUNDWATER  
APRIL AND AUGUST 1990

Source: Levine-Fricke, 1990





Source: Levine-Fricke, 1990



## 3.0 HEALTH RISK ASSESSMENT

### 3.1 INTRODUCTION

This section presents the health risk assessment for the Sola Optical Site in Petaluma, California. The purpose of the risk assessment is to characterize the potential human health risks associated with the site. This assessment addresses potential risks from the site under feasible future land use assuming continued operation of the groundwater extraction system.

This chapter is organized in the following sections:

- Identification of Chemicals of Potential Concern. Identifies the chemicals evaluated in the assessment.
- Exposure Assessment. Identifies potential pathways by which exposures could occur and characterizes the potentially exposed populations and the frequency and duration of these exposures.
- Toxicity Assessment. Summarizes the toxicity of the chemicals of concern and the relationship between magnitude of exposure and adverse effects.
- Health Risk Characterization. Integrates the toxicity and exposure assessments to estimate the potential risks to public health from exposure to the selected chemicals of concern.
- Uncertainties, Limitations, and Assumptions. Summarizes the basic assumptions, data limitations, and methodology used in the risk assessment.

This risk assessment was performed in accordance with the following guidance and advisories:

- Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Part A. Interim Final. December 1989 (U.S. EPA 1989a).
- U.S. EPA Region IX risk assessment guidance (U.S. EPA 1989b).
- U.S. EPA risk assessment guidelines (U.S. EPA, 1986b-f).

## **3.2 IDENTIFICATION OF CHEMICALS OF POTENTIAL CONCERN**

The risk assessment is based on the groundwater, soil, and soil-gas data collected in 1990 by Levine-Fricke (1990) and split groundwater and soil samples taken by U.S. EPA during the site investigations (Section 2.0). These data have not been independently evaluated by CH2M HILL; however, U.S. EPA split samples have been validated by U.S. EPA data validation staff. VOCs were detected in groundwater, subsurface soil, and soil-gas at the site. All chemicals of potential concern are presented by medium of occurrence in Table 3-1.

## **3.3 EXPOSURE ASSESSMENT**

Exposure assessment is the determination or estimation of the exposure magnitude, frequency, duration, and route. This section identifies the potentially exposed human populations and the means by which these individuals can come into contact with chemicals from the Sola Optical site. The risk assessment addresses exposures that could result from potential future uses of the site and surrounding area.

Exposure is defined as the contact of an organism with a chemical or physical agent. The magnitude of exposure is determined by measuring or estimating the amount of a chemical available at the exchange boundaries (i.e., the lungs, intestines, and skin). When contaminants migrate from the site to an exposure point (i.e., a location where receptors can come into contact with contaminants), or when a receptor comes into direct contact with waste or contaminated media at the site itself, exposure can occur.

### **3.3.1 POTENTIALLY EXPOSED POPULATIONS**

The site is currently occupied by Sola Optical USA, Inc. which has been manufacturing optical lenses at the site since 1978 (Levine-Fricke, 1990). The current source of tap water at the site is City-supplied water. The site is in an area of mixed light industry and residential development. It is assumed that future uses of this site could include residential development and use of site groundwater as a drinking water source. Therefore, future onsite residents could be potentially exposed to site contaminants.

### **3.3.2 EXPOSURE PATHWAY ANALYSIS**

An exposure pathway is the route by which a receptor makes contact with a contaminant source. Exposure may occur when chemicals migrate or are mechanically moved from the site to an exposure point (i.e., a location where receptors can come into contact with chemicals) or when a receptor comes into direct contact with materials containing the chemicals of concern left in place. An exposure pathway is complete (i.e., there is an exposure) if a receptor takes in chemical constituents through ingestion, inhalation, or dermal absorption (contact with skin).

A complete exposure pathway has four elements:

- Chemical source with a mechanism for chemical release
- Environmental transport medium
- Exposure point (receptor location)
- Feasible route of exposure (ingestion, inhalation, and dermal absorption)

Each of these elements of an exposure pathway, as they apply to the Sola Optical site, are described below.

### **3.3.2.1 Chemical Sources, Release, and Transport**

Potential exposure sources at the Sola Optical site consist of groundwater and subsurface soil that contain the VOCs of potential concern (Table 3-1). Potential mechanisms for chemical release and transport are as follows:

**Air.** Air migration of VOCs can occur following volatilization of chemicals from soil or water. Volatilization of compounds from soil and water are driven by vapor pressure and the Henry's law constant for a given chemical, respectively. Chemicals can volatilize from subsurface soil or groundwater, into soil pore spaces, and migrate as a gas up through the unsaturated zone into surface air. In Section 2.5.2., the VOC concentrations in a house built on the Sola Optical site were predicted based on site groundwater, soil, and soil-gas investigations (Table 2-8).

**Groundwater.** VOCs from soil could potentially migrate into the groundwater beneath the site. The VLEACH and AT123D models were used by Levine-Fricke (1991) to predict VOC concentrations in groundwater based on soil VOC concentrations. These results were presented in Section 2.5.1.

### **3.3.2.2 Potential Exposure Pathways**

Potential routes of exposure to VOCs at the Sola Optical site are listed in Table 3-2. Identification of potential exposure pathways takes into account contaminant migration pathways and receptor activities. These pathways were evaluated to determine if they are or have the potential to be complete exposure pathways.

Exposure pathways retained for final consideration assume that future land use at the site will include residential development. Under this scenario, it is further assumed that groundwater at the site could potentially be used for domestic purposes. Human exposure to contaminants can occur through the use of groundwater as a drinking water supply. In residences, people can be exposed to contaminants from ingestion of the water used for drinking and cooking. They can also be exposed through dermal absorption of contaminants, primarily during bathing and showering, and inhalation of volatile compounds released from the water into the household air during showering, bathing, cooking or by the use of household appliances such as washing machines.

Exposure to contaminants in groundwater and subsurface soil can occur through transport of VOCs through the foundation of a house on the site. Residents may also be exposed to contaminants in subsurface soil which have migrated downward to groundwater at the site.

### 3.3.3 QUANTIFICATION OF EXPOSURE

This section summarizes the factors used to quantify exposure. The detailed methodology for quantifying exposure is presented in Appendix A.

#### 3.3.3.1 Exposure Estimation Methods

Exposure is defined as the contact of an organism with a chemical or physical agent. In this assessment, exposure (or intake) is normalized for time and body weight and is expressed as milligrams of chemical per kilogram of body weight per day (mg/kg-day). Six basic factors are used to estimate intake: exposure frequency, exposure duration, contact rate, chemical concentrations, body weight, and averaging time.

Exposure can be described by the following general equation:

$$\text{Exposure} = \frac{\text{Concentration} \times \text{Contact Rate} \times \text{Exposure Frequency} \times \text{Exposure Duration}}{\text{Body Weight} \times \text{Averaging Time}}$$

**Exposure Estimation for Carcinogenic Effects.** The intake of a chemical evaluated for carcinogenic health effects (i.e., lifetime average chemical intake) is calculated by prorating the total cumulative dose of the chemical over an averaging time of an entire life span (assumed to be 70 years) (U.S. EPA, 1989a). The selection of an averaging time that spans a lifetime is based on U.S. EPA guidance: "The approach for carcinogens is based on the assumption that a high dose received over a short period of time is equivalent to a corresponding low dose spread over a lifetime" (U.S. EPA, 1989a). By convention, a "typical" individual with a lifetime average body weight of 70 kg (i.e., an adult male) is assumed (U.S. EPA, 1989a).

**Exposure Estimation for Noncarcinogenic Effects.** The intake of chemicals evaluated for noncarcinogenic health effects is estimated over an averaging time dependent on the assessed toxic effect (i.e., health effect). This assessment evaluates the effects of chronic exposure to chemicals on the basis of systemic toxic effects. The averaging time used is based on the estimated period of exposure.

For any given exposure setting, the noncarcinogenic risk is evaluated for a target receptor; the group that receives the reasonable maximum exposure or intake of a chemical based on an exposure per kilogram of body weight per day. For example, in a residential setting where drinking water ingestion is a concern, small children (i.e., toddlers) are the target group. They are the age group expected to have the greatest potential exposure (on the basis of milligrams of chemical per kilogram of body weight) because of their activity patterns and low body weights.

**Chemical Concentrations.** A future onsite well would likely be screened throughout the depth of the well, and therefore, contaminated concentrations throughout the depth of the well would be averaged, weighted by the relative hydraulic conductivities of the water producing zones. In this assessment, all onsite Levine-Fricke monitoring wells were used to evaluate groundwater exposure through household use of drinking water.

Chemical concentrations used to evaluate groundwater exposures were the 95 percent upper confidence limit on the arithmetic mean of the data set based on U.S. EPA exposure guidance (U.S. EPA, 1989a). In instances when a chemical was not detected in a sample, a value equal to one-half the detection limit was used in the estimation of the mean. The arithmetic mean, standard deviation, and 95 percentile upper confidence on the arithmetic mean groundwater concentrations are summarized in Table 3-3.

Future exposure to groundwater contamination from chemicals migrating from soil to groundwater was also evaluated. Chemical concentrations used in these calculations were the maximum concentrations predicted by Levine-Fricke using VLEACH and mixing cell models (Section 2.5.1.).

To evaluate inhalation exposures to VOCs which have been transported from groundwater or soil through the foundation of a house, the maximum air concentrations estimated in Section 2.5.2 (Table 2-9) were used.

### **3.3.3.2 Exposure Assumptions--General Principles**

The following sections present the intake values used in estimating exposure to chemicals in household tap water and exposure to VOCs in household air. Table 3-4 summarizes the intake values used in this assessment.

#### **Exposure to Chemicals in Household Tap Water**

Human exposure to contaminants in water used in residences can occur through three routes of exposure: ingestion, inhalation, and dermal absorption.

**Ingestion.** People can be directly exposed to contaminants through the ingestion of tap water. The degree of exposure to contaminants through ingestion depends on the amount of water ingested on a daily basis. The amount ingested is a result of several factors including age, activity, dietary patterns, and climate. Ingestion results from direct ingestion of tap water, ingestion of fluids made with tap water (e.g., coffee, tea, reconstituted fruit concentrates), and food cooked with water (e.g., soups).

U.S. EPA currently uses standard water intake rates of 2 liters/day for adults and 1 liter/day for infants (U.S. EPA, 1980 and U.S. EPA, 1989a). Although individuals may ingest many times this amount, this assessment adopts the EPA assumptions of 2 liters/day for 70-kg adults and 1 liter/day for 10-kg infants. Exposures in residential

settings are assumed to occur for a duration of 30 years (U.S. EPA, 1989b) with a 70-kg body weight (bw).

**Inhalation.** Individuals can also be exposed to VOCs transferred from tap water to the air from showers, baths, toilets, dishwashers, washing machines, and cooking. Studies have suggested that exposure to volatile chemicals from inhalation can be as great as or greater than from ingestion alone. Studies on indoor radon, a gas thought to behave like VOCs, have indicated enrichment of indoor air from radon released from tap water.

There is not a standard intake assumption to estimate residential exposure to volatile compounds released from tap water. Several variables can affect the degree of exposure that could occur. For example, exposures that take place in the shower are controlled by the temperature of the water, the type of shower head, duration of the shower, size of the shower space, and the air exchange rate between the shower and the rest of the bathroom or house. Individual chemicals will volatilize at different rates. The air exchange rate between the house and the outdoors is another factor. Several estimates of potential inhalation exposures have been made and summarized below.

Cothorn et al. (1985) suggested that respiratory uptake of VOCs is approximately equal to oral uptake (assuming standard U.S. EPA ingestion estimates). Dixon et al. (1985) estimated inhalation exposure during a shower to be 2.6 times ingestion for selected VOCs. Modeling by Shehata (1985) indicated for benzene an inhalation exposure during showering of 0.92 to 1.9 times that of ingestion exposures. Andelman (1985) conducted experiments on trichloroethene transfer in a model shower stall and estimated inhalation exposures of up to six times that of ingestion. Foster and Chrostowski (1986) modeled VOC release to a shower/bathroom and estimated the ratio of inhalation exposure during showering to ingestion of drinking water to be in the range of 1.1 to 2.

Recently, McKone (1987) estimated inhalation exposure to volatile compounds in a household over a 24-hour period. He used a three-compartment model to simulate the release of seven VOCs into a home. He developed indoor air profiles to reflect changing concentrations over time and combined these data with estimates of individual activities to estimate exposure. He estimated that inhalation exposures would be 1.5 (average) to 6 (upper-bound estimate) times that of ingestion. His estimated concentrations were in line with the limited number of studies with measured concentrations.

To evaluate potential exposures from the inhalation of VOCs released from tap water at the site, this assessment assumes that the intake of volatile contaminants through inhalation will be equal to the intake of contaminants estimated to occur by the ingestion of drinking water. Because of the uncertainty associated with this estimate of exposure, however, risks estimated for inhalation exposures will likely have a lower degree of confidence than those estimated for drinking water ingestion.



**Dermal Absorption.** Another potential route of exposure associated with water use is dermal absorption of contaminants. Dermal absorption could occur during bathing, showering, food preparation, and washing dishes.

Skin is not very permeable and, therefore, is a relatively good lipid barrier separating humans from their environment. However, some chemicals can be absorbed by the skin in sufficient quantities to produce systemic effects (Klaasen et al., 1986). Absorption of a chemical requires passage through the outer skin layer, the stratum corneum. Passage through this barrier is the rate limiting step in dermal absorption. It appears that, in general, toxicants move across the stratum corneum by passive diffusion following Fick's Law.

Specifically, however, many factors influence the absorption of chemicals across the skin layer. These include the health of the skin, the location of the area of skin exposed, hydration of the skin, time of exposure, molecular size of the chemical, lipid solubility, thickness of the skin, temperature, and the type of solvent the solute is dissolved in. Because dermal absorption is a complex activity controlled by many factors, it is difficult to precisely predict exposures from this route.

Dermal absorption of volatile compounds in pure form or dilute solution has been observed and documented by several studies (Dutkiewitz and Tyros, 1967; Dutkiewitz and Tyros, 1968; Scheuplein and Blank, 1971; Scheuplein and Blank, 1974). There have been varying estimates on the amount of chemical intake that can result from dermal absorption of chemicals in water (Brown et al., 1984; and Levin et al., 1984). Cothorn et al. suggested that intake through dermal absorption would normally be much less (by several orders of magnitude) than either the ingestion or inhalation routes in a household setting where exposure comes from the water supply. Estimation of household exposures by Foster and Chrostowski (1986) yielded similar results.

It has been suggested that the rate (flux) of water across the skin can be used as a surrogate means for estimating dermal absorption of environmental concentrations of chemicals in water (U.S. EPA, 1989a). A water flux rate of 0.2 to 0.4 mg/cm<sup>2</sup>/hr has been reported in the literature (Scheuplein and Blank, 1971). This approach can be applied to a hypothetical chemical, with the following assumptions:

Concentration in water	1,000 µg/l
Ingestion rate	2 liters/day
Body weight	70 kg
Water flux	0.4 mg/cm <sup>2</sup> /hr
Surface area	18,000 cm <sup>2</sup>
Shower or bath duration	30 minutes
Percent submerged	85 percent

Intakes for ingestion and dermal absorption were estimated, with the following results:

$$\begin{aligned}\text{Ingestion} &= \text{Concentration } (\mu\text{g/l}) \times \text{Intake (l/day)} \times 1/\text{body weight (kg)} \\ &= 1,000 \mu\text{g/l} \times 2 \text{ l/day} \times 1/70 \text{ kg} \\ &= 28.6 \mu\text{g/kg/day}\end{aligned}$$

$$\begin{aligned}\text{Dermal Absorption} &= \text{Concentration } (\mu\text{g/l}) \times \text{flux (mg/cm}^2\text{/hr)} \times \\ &\quad \text{surface area (cm}^2\text{)} \times \text{duration (hr/day)} \times \\ &\quad \text{fraction submerged} \times \text{unit correction (1} \\ &\quad \text{liter/1,000,000 mg)} \times 1/\text{body weight (kg)} \\ &= 1,000 \mu\text{g/l} \times 0.4 \text{ mg/cm}^2\text{/hr} \times 18,000 \text{ cm}^2 \times 0.5 \text{ hr/day} \\ &\quad \times 0.85 \times 1 \text{ liter/1,000,000 mg} \times 1/70 \text{ kg} \\ &= 0.044 \mu\text{g/kg/day}\end{aligned}$$

As this demonstrates, estimating dermal absorption by this method will typically yield dermal absorption exposures several orders of magnitude lower than exposures estimated for ingestion.

Another approach is to estimate a permeability constant for flux across the skin (Brown et al., 1984). There are, however, a limited number of compounds for which permeability constants have been estimated and these constants are not usually for dilute solutions.

This risk assessment does not quantitatively estimate dermal absorption from household water use because of the uncertainty associated with making a quantitative estimate of such an exposure. However, because the existing information in the literature and the above application of the water flux method suggest that contaminant intake through dermal absorption could be several orders of magnitude less than through ingestion of tap water, in this assessment dermal absorption in the residential use setting is considered not likely to be a significant route of exposure.

### **Exposure to Chemicals in Household Air**

Exposure to contaminants in air could result from transport of VOCs from groundwater or subsurface soil through the foundation of a house. To estimate exposure to airborne chemicals, a 24-hour inhalation rate of 20 m<sup>3</sup>/day (U.S. EPA, 1989c) was assumed.

#### **3.3.3.3 Exposure Point Concentrations**

Exposure point concentrations can be estimated by direct measurement at a point of contact or by modeling contaminant release and transport to the exposure point. In this assessment, it is assumed that exposure point concentrations are constant over

time. This approach does not reflect potential changes in contaminant concentration because of environmental transport, transfer, or transformation processes.

### **3.4 TOXICITY ASSESSMENT**

Toxicity assessment has two general steps. The first step, hazard identification, is the process of determining what adverse health effects, if any, could result from exposure to a particular chemical. The second step, dose-response evaluation, quantitatively examines the relationship between the level of exposure and the incidence of adverse health effects in an exposed population.

This section summarizes the toxicological effects associated with exposure of individuals to the chemicals of concern and the dose-response relationships for those chemicals.

#### **3.4.1 HAZARD IDENTIFICATION**

For the purpose of this risk assessment, human health effects are divided into two categories: carcinogenic and noncarcinogenic effects. Consequently, human health risks are evaluated in this assessment in terms of carcinogenic and noncarcinogenic risks. Chemicals with carcinogenic risk frequently have noncarcinogenic effects, too.

##### **Carcinogenic Effects**

Carcinogenesis is generally thought to be a phenomenon for which risk evaluation based on presumption of a threshold is inappropriate. For carcinogens, U.S. EPA assumes (conservatively) that a small number of molecular events can evoke changes in a single cell that can eventually lead to cancer. This hypothesized mechanism for carcinogenesis is referred to as "nonthreshold" because there is believed to be essentially no level of exposure to such a chemical that does not pose a finite probability, however small, of generating a carcinogenic response.

U.S. EPA has developed a carcinogen classification system (U.S. EPA, 1986a) that uses a weight-of-evidence approach to classify the likelihood of a chemical being a human carcinogen. Information considered in developing the classification includes human studies of the association between cancer incidence and exposure as well as long-term animal studies under controlled laboratory conditions. Other supporting evidence considered includes short-term tests for genotoxicity, metabolic and pharmacokinetics properties, toxicological effects other than cancer, structure-activity relationships, and physical and chemical properties of the chemical. Chemicals are classified by U.S. EPA as:

- A--Human carcinogen
- B1--Probable human carcinogen; limited human data are available

- B2--Probable human carcinogen; sufficient evidence in animals and inadequate or no evidence in humans
- C--Possible human carcinogen
- D--Not classifiable as to human carcinogenicity
- E--Evidence of noncarcinogenicity for humans

### **Noncarcinogenic Effects**

Chemicals causing noncarcinogenic effects (i.e., systemic toxins) are believed to exhibit a level of exposure (from above zero to some finite value) that can be tolerated by the organism without causing an observed health effect.

Noncarcinogenic health effects include a variety of toxic effects on body systems, ranging from renal toxicity (toxicity to the kidney) to central nervous system disorders. It is believed that organisms might have protective mechanisms that must be overcome before a toxic endpoint (effect) is manifest. The toxicity of a chemical is assessed through a review of toxic effects noted in short-term (acute) animal studies, long-term (chronic) animal studies, and epidemiological investigations.

### **Toxicity Profiles**

Summary toxicity profiles are presented in Table 3-5. The profiles describe four categories of potential toxic effects: acute toxicity, chronic toxicity, carcinogenicity, and other effects. Detailed profiles can be found in the toxicological literature. Although toxicity profiles are not provided for all chemicals, the exclusion of a chemical is not meant to imply that exposure to these chemicals is without effects.

### **3.4.2 DOSE-RESPONSE RELATIONSHIPS**

Toxicity depends on the dose or concentration of the substance (i.e., the dose-response relationship). Toxicity values are a quantitative expression of the dose-response relationship for a chemical. Toxicity values take the form of reference doses (RfDs) and cancer slope factors (CSFs), both of which are specific to exposure via different routes.

Two sources of toxicity values were used. The primary source is the U.S. EPA's Integrated Risk Information System (IRIS) database (U.S. EPA, 1990a). IRIS is a U.S. EPA data base containing up-to-date health risk and U.S. EPA regulatory information. IRIS contains only those RfDs and slope factors that have been verified by U.S. EPA work groups and is considered by U.S. EPA to be the preferred source of toxicity information.

If a toxicity value was not available through IRIS, the next data source consulted was the most recently available Health Effects Assessment Summary Tables (HEAST) issued by the U.S. EPA's Office of Research and Development (U.S. EPA, 1990b). HEAST summarizes interim (and some verified) RfDs and CSFs.

**Reference Dose.** The toxicity value describing the dose-response relationship for noncarcinogenic effects is the reference dose (RfD). The U.S. EPA (U.S. EPA, 1989a) defines RfDs in the following manner:

In general, the RfD is an estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure to the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. The RfD is generally expressed in units of milligram per kilogram of body weight per day (mg/kg-day).

The RfDs used in this risk assessment are presented in Table 3-6. Inhalation RfDs were not available for some of the chemicals present at the Sola Optical site. In the absence of chemical-specific inhalation RfDs, oral RfDs were used.

**Slope Factor.** The dose-response relationship for carcinogens is expressed as a cancer slope factor (CSF). Generally, the slope factor is a plausible upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime. The slope factor is usually, but not always, the upper 95 percent confidence limit of the slope of the dose-response curve and is expressed as inverse of milligrams of chemical per kilogram of body weight per day (mg/kg-day)<sup>-1</sup>. The slope factor value represents an upper 95 percent confidence limit of the probability of a response per unit intake of a chemical over a lifetime (i.e., there is only a 5 percent chance that the probability of a response could be greater than the estimated value on the basis of the experimental data and model used).

For practical reasons, risk at low exposure levels is difficult to measure directly either by animal experiments or epidemiologic studies (U.S. EPA, 1984). The development of a slope factor generally entails applying a model to the available data set and using the model to extrapolate from the relatively high doses administered to experimental animals (or exposures noted in epidemiologic studies) to lower exposure levels expected for human contact in the environment. A basic assumption is that, if a carcinogenic response occurs at the dose levels used in the study, a response will occur at all lower doses.

The approach used by the U.S. EPA to estimate the slope factor from animal studies or human data assumes a dose-response relationship with no threshold. There is uncertainty and conservatism built into the EPA's risk extrapolation approach. EPA has stated that cancer risks estimated by this method produce an estimate that provides a rough but plausible upper limit of risk: i.e., it is not likely that the true risk would be much more than the estimated risk, but it could be considerably lower (U.S. EPA,

1989a). Therefore, the actual risk will most likely be in the range between zero and the calculated quantity.

The CSFs used in this risk assessment are presented in Table 3-6.

### **3.5 HEALTH RISK CHARACTERIZATION**

This section presents an evaluation of the potential risks to public health associated with the Sola Optical site. Exposure situations are evaluated by estimating the carcinogenic and noncarcinogenic risks associated with them. To estimate risks, it was assumed that exposure remains constant over the exposure periods assessed (i.e., chemical concentrations and intake levels are constant).

#### **3.5.1 RISK ESTIMATION METHODOLOGY**

This section summarizes the approach used in developing the human health risk estimates presented in this section. Appendix B presents a more detailed description of the methodology used.

##### **3.5.1.1 Noncarcinogenic Risks**

Noncarcinogenic risk is assessed by comparing the estimated daily intake of a contaminant to its RfD. This comparison serves as a measure of the potential for noncarcinogenic health effects.

The estimated intake of each chemical through an individual route of exposure is divided by its RfD. The resulting quotients are termed noncancer hazard quotient. When the hazard quotient exceeds one (i.e., intake exceeds RfD), there is potential for health concern.

To assess the potential for noncarcinogenic effects posed by multiple chemicals, a "hazard index" approach has been adopted (U.S. EPA, 1989a). The method assumes dose additivity. Hazard quotients are summed to provide a hazard index. When the hazard index exceeds one, there is potential for health risk. If a single hazard quotient exceeds one, the hazard index will exceed one. The hazard index can exceed one even if no single chemical intake exceeds its reference dose. If this occurs, the chemicals may be segregated by similar effect or target organ to determine the potential health risks. Separate hazard indexes may be derived for each effect, if any exceed one.

##### **3.5.1.2 Carcinogenic Risks**

The potential for carcinogenic effects was evaluated by estimating excess lifetime cancer risk, which is the incremental increase in the probability of developing cancer during one's lifetime over the background probability of developing cancer (i.e., if no

exposure to site contaminants occurred). For example, a  $1 \times 10^{-6}$  excess lifetime cancer risk means that for every 1 million people exposed to the carcinogen throughout their lifetime (which is typically assumed to be 70 years) at the defined exposure conditions, the average incidence of cancer is increased by one extra case of cancer. Because of the methods followed by U.S. EPA in estimating CSFs, the excess lifetime cancer risks estimated in the assessment should be regarded as upper bounds on the potential cancer risks rather than accurate representations of true cancer risk. The actual risks could be as low as zero.

Although synergistic or antagonistic interactions might occur among chemicals at the site, at this time there is insufficient information in the toxicological literature to predict quantitatively the effects of such interactions. Therefore, consistent with EPA guidelines on chemical mixtures (U.S. EPA, 1986d), carcinogenic risks were treated in the assessment as additive within a route of exposure.

### **3.5.2 ESTIMATED RISKS--QUANTITATIVE ASSESSMENT**

Exposure pathway risks (carcinogenic and noncarcinogenic) were calculated for each chemical of potential concern. Risks for individual chemicals were then added to estimate a multi-chemical risk (carcinogenic or noncarcinogenic) for an exposure pathway. Estimated risks for exposure to site groundwater are presented in Table 3-7 and for exposure to VOCs inside a house are presented in Table 3-8. Detailed calculations are presented in Appendix B.

The exposure scenario for the Sola Optical site assumes a future resident would come in contact with groundwater at the site through household use of tap water. The estimated excess lifetime cancer risk for reasonable maximum ingestion and inhalation exposures from the use of tap water, presented in Table B-1, were  $5 \times 10^{-5}$  and  $9 \times 10^{-5}$ , respectively. The total estimated lifetime cancer risk is  $1 \times 10^{-4}$ . This risk is based on 1,1-dichloroethene, the only carcinogenic (Class C) chemical with a quantitative slope factor detected in groundwater.

Noncarcinogenic exposure levels did not exceed the reference doses. The hazard index for ingestion of tap water and inhalation of VOCs released from tap water, presented in Table B-2, are 0.07 each. The total hazard index is 0.2.

Ten chemicals were detected in the W-wells during the April-May and August-September, 1990 groundwater sampling events. These chemicals included chloroform, 1,1-DCA, 1,2-DCA, 1,1-DCE, Freon 11, Freon 113, PCE, 1,1,1-TCA, 1,1,2-TCA and TCE. Toluene, which was detected in LF-wells, was not sampled for in the W-wells. Five of the chemicals detected in the W-wells (chloroform, 1,2-DCA, PCE, 1,1,2-TCA, and TCE) were detected in less than 5 percent of the total samples taken during the sampling period and, therefore, were not considered in this assessment.

The W-well data for 1,1-DCA, 1,1-DCE, Freon, and 1,1,1-TCA, in combination with the LF-well data for these same chemicals, would result in an increase in the 95 percent

confidence limit on the arithmetic mean concentration used in the risk calculations. The 95 percent confidence limit would increase from 0.0011 mg/l to 0.024 mg/l for 1,1-DCA, 0.0061 mg/l to 0.11 mg/l for 1,1-DCE, 0.00063 mg/l to 0.0092 mg/l for Freon 113, and 0.0029 mg/l to 0.019 mg/l for 1,1,1-TCA. Using these numbers in the risk calculations would increase the total estimated lifetime cancer risk due to tap water ingestion and inhalation exposures from  $1 \times 10^{-4}$  to  $3 \times 10^{-3}$ . The total hazard index would increase from 0.2 to 3.0. The major contributor to both estimated cancer and noncancer risks is 1,1-DCE.

In addition to the above chemicals, Freon 11 was detected in W-wells and not in the LF-wells. The 95 percent confidence limit on the arithmetic mean concentration for Freon 11 is 0.0009 mg/l. Freon 11 has a chronic oral RfD of  $3 \times 10^{-1}$  and a chronic inhalation RfD of  $2 \times 10^{-1}$  (U.S. EPA, 1990b). Addition of this chemical to the risk assessment would increase the total hazard index by 0.0007.

Modeling of transport from soil to groundwater (Section 2.5.1.) predicted a maximum groundwater concentration at the source of 0.41  $\mu\text{g/l}$  ( $4.1 \times 10^{-4}$  mg/l) for 1,1-DCA and 0.70  $\mu\text{g/l}$  ( $7 \times 10^{-4}$  mg/l) for 1,1-DCE. (No other chemicals were modeled.) Although both of these chemicals are listed by the U.S. EPA as class C carcinogens, only 1,1-DCE has a cancer slope factor. A 30-year exposure to 1,1-DCE at a concentration of 0.70  $\mu\text{g/l}$  would correspond to an excess lifetime cancer risk of  $2 \times 10^{-5}$ , with exposures by ingestion of drinking water contributing  $5 \times 10^{-6}$  and exposure through inhalation contributing  $1 \times 10^{-5}$ .

Before use of the City of Petaluma Station 5 well was discontinued in 1988, concentrations of 1,1-DCE were detected at a maximum of 0.002 mg/l. Continued exposure to 1,1-DCE at this concentration under the same exposure scenario used above would correspond to an estimated excess lifetime cancer risk of  $4 \times 10^{-5}$ . This exposure pathway is currently incomplete since the Station 5 well is not operating at this time.

Estimated risks from exposure to contaminants transported through the foundation of a house are presented in Table 3-8. The estimated excess lifetime cancer risk due to inhalation of these contaminants is  $9 \times 10^{-6}$ , contributed mainly by exposure to 1,1-DCE (Table B-3). The hazard index for this route of exposure is 0.002 (Table B-4). These estimates are likely to be conservative since the estimates of VOC concentrations in the house were based on the maximum chemical concentrations found in soil-gas, groundwater, and soil.

### 3.6 UNCERTAINTIES, LIMITATIONS, AND ASSUMPTIONS

Uncertainties in this risk assessment are due to uncertainties in the risk assessment process in general (i.e., the toxicological data base), specific uncertainties in characterizing the site, and uncertainties associated with describing exposures. The uncertainties



in this risk assessment are summarized in Table 3-9. This risk assessment is subject to uncertainty from a variety of sources, including:

- Sampling and analysis
- Exposure estimation
- Toxicological data

Uncertainty associated with sampling and analysis include the inherent variability (standard error) in the analysis, representativeness of the samples, sampling errors, and heterogeneity of the sample matrix. While the quality assurance/quality control serves to reduce these errors, it can not eliminate all errors associated with sampling and analysis.

The estimation of exposure required numerous assumptions to describe potential exposure situations. There are a number of uncertainties regarding likelihood of exposure, frequency of contact with contaminated media, the concentration of contaminants at exposure points, and the time period of exposure. Exposure estimations were based on human activity patterns reported in guidance documents (U.S. EPA, 1989a, 1989c).

The toxicological data base is also a source of uncertainty. The EPA outlined some of the sources of uncertainties in its Guidelines for Carcinogen Risk Assessment (U.S. EPA, 1986b). They include extrapolation from high to low doses and from animals to humans; species differences in uptake, metabolism, and organ distribution; species differences in target site susceptibility; and human population variability with respect to diet, environment, activity patterns, and cultural factors.

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<b>Table 3-1</b> <b>Chemicals Detected in Groundwater, Subsurface Soil, or Soil-Gas</b> <b>during 1990 Sampling at the Sola Optical Site<sup>a</sup></b>			
<b>Chemical</b>	<b>Groundwater</b>	<b>Subsurface Soil</b>	<b>Soil-Gas</b>
Acetone	--	X	X
Butanone	--	X	--
1,1-Dichloroethane	X	X	X
1,2-Dichloroethane	--	X	--
1,1-Dichloroethene	X	X	X
Freon 113	X	--	X
4-Methyl-2-pentanone	--	X	--
Tetrachloroethene	--	X	X
Toluene	X	X	--
1,1,1-Trichloroethane	X	X	X
1,1,2-Trichloroethane	--	X	--
Trichloroethene	--	X	X
<sup>a</sup> Taken from Tables 2-3, 2-6, and Figure 2-6.			

<b>Table 3-2</b> <b>Screening of Potential Exposure Pathways for Future Onsite Residents</b>					
<b>Media</b>	<b>Release</b>	<b>Exposure Route</b>	<b>Receptor</b>	<b>Rationale</b>	<b>Exposure Potentially Feasible</b>
Subsurface Soil	Volatilization	Inhalation	Future Onsite Resident	VOC diffusion through foundation of house	Yes
	Migration to Groundwater	Ingestion Inhalation Dermal	Future Onsite Resident	Diffusion through soil to groundwater	Yes
Groundwater	Direct Contact	Dermal/Ingestion	Future Onsite Resident	Water could potentially be used for domestic use.	Yes
	Volatilization	Inhalation	Future Onsite Resident	Water could potentially be used for domestic use. Residents could be exposed to VOCs released from water into household air.	Yes
			Future Onsite Resident	Diffusion from groundwater through soil through the foundation of a house.	Yes

<b>Table 3-3</b> <b>Chemicals of Potential Concern in Groundwater</b>				
Chemical	Sample Size	Concentration (mg/l) <sup>a</sup>		
		Mean	Standard Deviation	95 Percentile
1,1-Dichloroethane	43	0.00074	0.0011	0.0011
1,1-Dichloroethene	43	0.0041	0.0067	0.0061
Freon 113	38	0.00042	0.00066	0.00063
Toluene	12	0.0018	0.0011	0.0025
1,1,1-Trichloroethane	43	0.0020	0.0029	0.0029
<sup>a</sup> Data taken from Table 2-3. Includes all onsite wells except LF-27.				

<b>Table 3-4</b> <b>Assumptions used in Future-Use Scenarios</b>	
<b>Parameter</b>	<b>Intake Value<sup>a</sup></b>
Ingestion Rate	1 liter/day (child) 2 liter/day (adult)
Inhalation Rate	20 m <sup>3</sup> /day (adult)
Body Weight	10 kg (child) 70 kg (adult)
Exposure Frequency Exposure Duration Years in Lifetime	365 days/year 30 years 25,550 days (70 years)
<sup>a</sup> Source: U.S. EPA, 1989a, 1989b, and 1989c.	

**Table 3-5  
Summary Toxicity Profiles**

<b>Chemical</b>	<b>Acute Toxicity Summary</b>	<b>Chronic Toxicity Summary</b>	<b>Cancer Potential</b>	<b>Other</b>
Toluene	Humans exposed by inhalation experimentally, occupationally, or by intentional abuse may exhibit excitation, then CNS depression and necrosis. Neurotoxic effects include nausea, fatigue, and incoordination at low levels and confusion, ataxia, and weakness at higher levels. In rats, irritation of mucous membranes and incoordination have been observed, as well as pulmonary irritation with subchronic exposure.	CNS effects have been reported in workers, such as disturbances in memory and thinking, psychomotor skills, visual accuracy, sensorimotor speed, and performance tests. Indications of cerebral and cerebellar dysfunction include tremors, ataxia, and equilibrium disorders, bizarre behavior, and emotional lability may occur. In cases of abuse, changes in liver and kidney function have been observed. In rats, a decrease in hematocrit has been reported.	Embryotoxicity and possible teratogenicity in mice have been reported in an abstract. In rats, skeletal retardation of offspring has been described.	
1,1,1-Trichloroethane (1,1,1-TCA)	Trichloroethane is a CNS depressant and may impair psychophysiological functions. Human fatalities have been reported following deliberate inhalation or occupational exposures; lung congestion was found.	Exposure by inhalation can produce liver damage in mice and affects drug metabolism in liver of rats.	Not indicated.	
1,1,2-Trichloroethane	1,1,2-Trichloroethane can injure the skin through defatting. It is a CNS depressant and can cause narcosis. Liver and kidney damage, sometimes severe, have been reported in laboratory animals.	In rats, mice, guinea pigs, and dogs, liver damage can occur after oral and inhalation exposures; effects include cloudy swelling, necrosis, and alterations in enzymes and glycogen content; centrilobular necrosis and fatty changes have been produced after intraperitoneal injections. Kidney damage may also occur. In humans, long-term exposure to vapor has been associated with gastric symptoms and lung and kidney effects.	Hepatocellular carcinomas and pheochromocytomas were reported in mice in a study by the National Toxicology Program; classified by EPA as Level C, possible human carcinogen.	More hepatotoxic than 1,1,1-trichloroethane; lower doses produced liver toxicity after single or repeated exposures in mice or rats.
Trichloroethene (TCE)	Exposure to TCE can cause depression of the CNS, including dizziness, headaches, incoordination similar to that induced by alcohol, nausea, vomiting, and unconsciousness.	Long-term inhalation exposure can affect liver and kidneys in animals. In humans, changes in liver enzymes have been associated with TCE exposure.	Exposure of mice (orally and by inhalation) and rats has produced increases in liver or lung or kidney tumors.	"Degreasers flush" has been described in TCE-exposed workers who consume alcohol.

Continued



**Table 3-5  
Summary Toxicity Profiles**

Chemical	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
1,2-Dichloroethane (1,2-DCA)	CNS depression, lung irritation, and injury to liver, kidney, and adrenal have been reported. Deaths in humans exposed by ingestion or inhalation may result in circulatory and respiratory failure.	Chronic exposure can cause liver degeneration and kidney damage in laboratory animals. Eye damage (necrosis of corneal epithelium) has been observed in dogs injected with 1,2-dichloroethane. Repeated exposures have been associated with anorexia, nausea, liver and kidney dysfunction, and neurological disorders in workers.	Carcinogenic in mice and rats exposed orally.	Mutagenic in some tests in bacteria, barley, and fruit flies.
1,1-Dichloroethene (1,1-DCE)	Liver appears to be principal target. Biochemical changes and necrosis in liver in fasted rats have been reported to develop rapidly after inhalation. Liver damage in fasted rats can occur after one oral dose. At high concentrations, inhalation of 1,1-DCE can cause CNS depression in humans and unconsciousness.	Described as "exquisite hepatotoxin" because it is more potent and faster acting than the classic hepatotoxin, carbon tetrachloride. Kidney injury can also occur at relatively low doses. Reports of health effects on workers exposed to 1,1-DCE include liver function abnormalities, headaches, vision problems, weakness, fatigue, and neurological sensory disturbances.	One group of investigators reported an increased incidence of kidney tumors in mice exposed by inhalation and possibly mammary tumors in rats. Tumor initiator activity in mouse skin following several treatments with phorbol as a promoter has been described.	Structure similar to vinyl chloride, a known human carcinogen; mutagenic in bacterial tests; may be fetotoxic in laboratory animals.
4-Methyl-2-Pentanone (Methyl Isobutyl Ketone; MIBK; Isopropyl Acetone; Hexone	Irritating to eyes, nose, and throat; defatting properties may cause skin dermatitis. MIBK is a central nervous system depressant and can produce weakness, headache, nausea, light-headedness, vomiting, dizziness, incoordination, and narcosis. Loss of appetite and diarrhea have also been reported with industrial exposures.	No distal axonopathy or related neurotoxicity was clearly associated with MIBK in several laboratory studies, although some investigators indicated that subtle behavioral alterations may occur. Kidney and liver weights and organ/body weight ratios were increased in rats inhaling MIBK in subacute or subchronic studies; reversible kidney damage including hyaline droplet degeneration and tubular necrosis has been observed in rats in one study. Insomnia, heart burn, intestinal pain, and enlarged livers have been experienced by a few workers; most effects appeared reversible.	Insufficient information.	One investigator reported that workers developed tolerance over the work week that was lost over the weekend. A low odor threshold (0.10 ppm) has been described; at 8 to 15 ppm MIBK is detectable.
Tetrachloroethene (Perchloroethylene)	Tetrachloroethene can depress the CNS and cause narcosis. It is irritating to mucous membranes and skin and can cause lung edema. Neurological effects on dry-cleaners have been reported.	Chronic exposure may result in pathological changes in liver of laboratory animals. It may also affect the kidney. In humans, inhalation exposure may produce irritation of respiratory tract, nausea, headache, sleeplessness, and abdominal pains. Fatalities have been reported.	Carcinogenic in laboratory animals. An increased incidence of cancers among dry-cleaning workers exposed to several solvents has been described.	

Continued

**Table 3-5**  
**Summary Toxicity Profiles**

Chemical	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
Acetone	Exposure to acetone can cause irritation of the eyes, skin, and respiratory tract. Depression of the central nervous system and narcosis can occur following inhalation of high concentrations of acetone; dryness of the mouth and throat, dizziness, nausea, incoordination, loss of speech, and even coma have been described in some cases of workers exposed occupationally to acetone.	In a study reported by EPA (IRIS, 31/88), kidney damage was observed in albino rats administered acetone by oral gavage. Kidney damage and metabolic changes have been noted in humans who ingested acetone. (Sax, 1989).		Acetone can potentiate the toxicity of other chemicals, particularly solvents. The hepatotoxicity of carbon tetrachloride can be increased greatly in the presence of acetone.
2-Butanone (Methyl Ethyl Ketone [MEK])	Acute inhalation exposure to methyl ethyl ketone (MEK) causes eye, skin, and nasal irritation. MEK is a central nervous system depressant after oral or inhalation exposure to high concentrations. Hepatotoxicity, including fatty accumulation and altered liver enzymes, has been reported in guinea pigs administered MEK intraperitoneally.	Insufficient information.	Insufficient information.	MEK has been implicated as a possible embryotoxic, fetotoxic, and teratogenic agent in rats exposed by inhalation. MEK may potentiate the neurotoxic effects of hexane or methyl n-butyl ketone and the hepatotoxic effects of carbon tetrachloride. MEK is readily absorbed by all routes of exposure.
1,1-Dichloroethane (1,1-DCA)	Central Nervous System (CNS) depression may occur when 1,1-dichloroethane is inhaled at high concentrations. Irritating to skin.	Data limited.	Limited evidence of increased incidence of mammary gland adenocarcinomas and hemangiosarcomas in female rats and hepatocellular carcinomas and benign uterine polyps in mice.	

Continued

**Table 3-5**  
**Summary Toxicity Profiles**

Chemical	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113 or CFC-113)	CFC-113 can depress the CNS and produce narcotic effects, anesthesia, and death (usually at approximately 100,000 ppm or 770,000 mg/m <sup>3</sup> for rodents following acute or subchronic exposures). In one study with two humans, psychomotor impairment, including decreased ability to concentrate, drowsiness, and dizziness, was reported after short exposures to high doses of CFC-113 (2,500 ppm, 0.5 to 1 hour); effects were reversible with cessation of exposure. Cardiotoxic effects have been observed in mice, dogs, rats, and monkeys, among them tachycardia, arrhythmia, and effects on blood pressure. Cardiac sensitization has been described in dogs inhaling CFC-113 in the presence of challenging doses of exogenous epinephrine. Some acute studies of laboratory animals have noted effects on liver, kidney, and thyroid.	Studies in dogs, rabbits, and rats report negative results; data base for chronic toxicity is limited. EPA reference dose is based on absence of effects in humans occupationally exposed for 2.77 years (or exposed to lower concentrations for 11 years).	Negative findings suggested in rat inhalation study; one case of mammary carcinoma noted in group of 20 female mice (compared to 0 in other groups) but statistical significance of data not evaluated.	Negative in limited mutagenicity tests. Possible indirect health effects of chlorofluorocarbons postulated, based on potential to deplete stratospheric ozone, possible increase of more damaging ultraviolet radiation reaching earth, and possible increases in incidence of skin cancers.

<p align="center"><b>Table 3-6</b> <b>Dose-Response Variables for Chemicals of Concern</b></p>										
Chemical	Systemic Toxicity (mg/kg/day)				Carcinogenic Potency (mg/kg/day) <sup>-1</sup>					
	Oral RfD	Reference	Inhalation RfD	Reference	Oral Slope Factor	Weight of Evidence <sup>a</sup>	Reference	Inhalation Slope Factor	Weight of Evidence <sup>a</sup>	Reference
Acetone	0.1	IRIS	--	--	--	--	--	--	--	--
Butanone	--	--	--	--	--	--	--	--	--	--
1,1-Dichloroethane	0.1	HEAST	0.1	HEAST	--	C	IRIS	--	C	IRIS
1,2-Dichloroethane	--	--	--	--	0.091	B2	IRIS	0.091	B2	IRIS
1,1-Dichloroethene	0.009	IRIS	--	--	0.6	C	IRIS	1.2	C	IRIS
Freon 113	30	IRIS	--	--	--	--	--	--	--	--
4-Methyl-2-pentanone	0.05	IRIS	0.02	HEAST	--	--	--	--	--	--
Tetrachloroethene	0.01	IRIS	--	--	0.051	B2	HEAST	0.0018	B2	HEAST
Toluene	0.3	IRIS	0.57	HEAST	--	--	--	--	--	--
1,1,1-Trichloroethane	0.09	IRIS	0.3	HEAST	--	--	--	--	--	--
1,1,2-Trichloroethane	0.004	IRIS	--	--	0.057	C	IRIS	0.057	C	IRIS
Trichloroethene	--	--	--	--	0.011	B2	HEAST	0.017	B2	HEAST
<p><sup>a</sup>Group B: Probable human carcinogen. Sufficient evidence in animals and inadequate or no evidence in humans. Group C: Possible human carcinogen. Limited evidence of carcinogenicity in animals in the absence of human data.</p> <p>Notes: HEAST Health Effects Assessment Summary Table, U.S. EPA 1990b. IRIS Integrated Risk Information System, U.S. EPA, 1990a. -- Information not available</p>										

**Table 3-7**  
**Risk Characterization--Groundwater Pathway**

<b>Chemical</b>	<b>Groundwater Concentration<sup>a</sup> (mg/l)</b>	<b>Cancer Risk Estimate<sup>b</sup></b>	<b>Hazard Index</b>
1,1-Dichloroethane	0.0011	--	0.0022
1,1-Dichloroethene	0.0061	$1.4 \times 10^{-4}$	0.14
Freon 113	0.00063	--	0.0000042
Toluene	0.0025	--	0.0013
1,1,1-Trichloroethane	0.0029	--	0.0042
<b>Total Risk</b>		$1 \times 10^{-4}$	<b>0.1</b>

<sup>a</sup>95 percent upper confidence limit on mean concentration from Table 3-3.

<sup>b</sup>Ingestion and inhalation routes summed together. The hazard index is based on a child exposure scenario.

<b>Table 3-8</b> <b>Risk Characterization--Air Pathway</b>			
<b>Chemical</b>	<b>Air Concentration<sup>a</sup> (µg/l)</b>	<b>Excess Lifetime Cancer Risk Estimate</b>	<b>Hazard Index</b>
Acetone	$4.0 \times 10^{-7}$	--	$1.1 \times 10^{-6}$
1,1-Dichloroethane	$9.9 \times 10^{-6}$	--	$2.8 \times 10^{-5}$
1,2-Dichloroethane	$5.9 \times 10^{-7}$	$6.6 \times 10^{-9}$	--
1,1-Dichloroethene	$5.8 \times 10^{-5}$	$8.5 \times 10^{-6}$	$1.6 \times 10^{-3}$
Freon 113	$6.5 \times 10^{-7}$	--	$6.2 \times 10^{-9}$
Tetrachloroethene	$4.0 \times 10^{-8}$	$8.8 \times 10^{-12}$	$1.1 \times 10^{-6}$
Toluene	$4.7 \times 10^{-7}$	--	$2.3 \times 10^{-7}$
1,1,1-Trichloroethane	$4.5 \times 10^{-6}$	--	$4.3 \times 10^{-6}$
1,1,2-Trichloroethane	$2.5 \times 10^{-6}$	$1.7 \times 10^{-8}$	$1.9 \times 10^{-4}$
Trichloroethene	$7.5 \times 10^{-8}$	$1.6 \times 10^{-10}$	--
<b>Total Risk</b>		<b><math>9 \times 10^{-6}</math></b>	<b>0.002</b>
<sup>a</sup> Maximum concentrations from Table 2-8.			

<p align="center"><b>Table 3-9</b> <b>Uncertainties Associated With Risk Estimations</b></p>		
<b>Uncertainty Factor</b>	<b>Effects of Uncertainty</b>	<b>Comment</b>
<b>I. Exposure Assessment</b>		
Exposure assumptions	May under- or overestimate risk	Assumptions regarding media intake, population characteristics, and exposure patterns may not characterize actual exposures.
Concentrations are assumed to be constant	May overestimate risk	Does not account for environmental fate, transport, or transfer, which may reduce chemical concentration.
Contaminant loss during sampling	May underestimate risk	May underestimate VOCs present.
Estimating inhalation exposures for released volatiles from tap water	May over- or underestimate risks	Several variables affect the degree of exposure which could occur including water temperature, etc.
Extent of sampling effort	May over- or underestimate risk	Sampling may not accurately characterize the medium being evaluated.
Chemical analysis procedures	May over- or underestimate risks	Systematic or random errors in the chemical analysis may yield erroneous data.
Use of delivered dose to estimate risks	May over- or underestimate risks	Assumes that the absorption of the chemical is the same as it was in the study that derived the toxicity value. Assumes that absorption is equivalent across species (animal to humans). Absorption may vary with age and species.
Population characteristics	May over- or underestimate risks	Assumes weight, lifespan, etc., are potentially representative for a potentially exposed population.
Intake	May underestimate risks	Assumes all intake of contaminants is from the exposure medium being evaluated (no relative source contribution).
<b>II. Toxicity Assessment</b>		
Slope factor	May overestimate risks	Slope factors are upper 95th percent confidence limits derived from a linearized model. Considered unlikely to underestimate risk.
Toxicity values derived from animal studies	May over- or underestimate risks	Extrapolation from animal to humans may induce error because of differences in absorption, pharmacokinetics, target organs, enzymes, and population variability.
Continued		

<b>Table 3-9</b> <b>Uncertainties Associated With Risk Estimations</b>		
<b>Uncertainty Factor</b>	<b>Effects of Uncertainty</b>	<b>Comment</b>
Toxicity values derived primarily from high doses, most exposures are at low doses	May over- or underestimate risks	Assumes linear at low doses. Tends to have conservative exposure assumptions.
Toxicity values	May over- or underestimate risks	Not all values represent the same degree of certainty. All are subject to change as new evidence becomes available.
Toxicity values derived from homogeneous animal populations	May over- or underestimate risks	Human population may have a wide range of sensitivities to a chemical.
<b>III. Risk Estimation</b>		
Estimation of risks across exposure routes	May under- or overestimate risk	Some exposure routes have greater uncertainty associated with their risk estimates than others.
No relative source contribution is accounted for	May underestimate risk	Does not account for nonsite-related sources of exposure.
Cancer risk estimates--no threshold assumed	May overestimate risks	Possibility that some thresholds do exist.
Cancer risk estimate--low dose linearity	May overestimate risks	Response at low doses is not known.



## Appendix A

# RISK ASSESSMENT METHODOLOGY

This appendix presents the methodology for estimating chemical intakes and carcinogenic and noncarcinogenic risks. These equations were used in this assessment to estimate risks to individuals exposed to contaminants at the Sola Optical site. The equations are from the U.S. EPA Risk Assessment Guidance for Superfund (U.S. EPA, 1989).

### ESTIMATION OF INTAKE

Equation A-1 presents a general equation for calculating chemical intake.

$$I = (C \times CR \times EF \times ED) / (BW \times AT) \quad (A-1)$$

where:

I	=	Chemical intake (mg/kg body weight-day)
C	=	Chemical concentration (e.g., mg/liter)
CR	=	Contact rate (e.g., liters/day)
EF	=	Exposure frequency (days/year)
ED	=	Exposure duration (years)
BW	=	Body weight (kg)
AT	=	Averaging time (days)

### Carcinogenic Effects

A lifetime average intake (or chronic daily intake) of the chemical is estimated for carcinogens. This acts to prorate the total cumulative intake over a lifetime. An averaging time (AT) or lifetime of 70 years is used for carcinogens.

Intake can change over a lifetime as body weight, contact rate, exposure frequency, and chemical concentrations change. Equation A-1 can be modified to address this issue:

$$I = (1/AT) \sum_{i=1}^M (C_i \times CR_i \times EF \times ED) / BW_i \quad (A-2)$$

where:

I	=	Chronic daily intake of the chemical (mg/kg body weight-day)
C <sub>i</sub>	=	Chemical concentration in i <sup>th</sup> time period (e.g., mg/liter)
CR <sub>i</sub>	=	Contact rate in i <sup>th</sup> time period (e.g., liters/day)
EF <sub>i</sub>	=	Exposure frequency in i <sup>th</sup> time period (days/year)

M	=	Number of time periods
ED	=	Exposure duration in $i^{\text{th}}$ time period (years)
BW <sub>i</sub>	=	Body weight in $i^{\text{th}}$ time period (kg)
AT	=	Averaging time (days)

U.S. EPA typically assumes a constant body weight (typically 70 kg) in estimating life-time cancer risk. This assumption would alter Equation A-2 to yield the following:

$$I = 1/(AT \times BW) \sum_{i=1}^M (C_i \times CR_i \times EF \times ED) \quad (A-3)$$

### Noncarcinogenic Effects

The intake of chemicals with noncarcinogenic effects is estimated over the appropriate exposure period or averaging time. The averaging time selected depends on the toxic endpoint being assessed.

When evaluating exposures to developmental toxicant, intakes are calculated by averaging over the exposure event (e.g., a day or single exposure incident). For acute toxicant, intakes are calculated by averaging over the shortest exposure period that could produce an effect, usually an exposure event or one day. For both situations, it can be assumed that the averaging time and the exposure period are equal. Therefore, Equation A-1 can be simplified to:

$$I = (C \times CR) / (BW) \quad (A-4)$$

where:

I	=	Chemical intake (mg/kg body weight-day)
C	=	Chemical concentration (e.g, mg/liter)
CR	=	Contact rate (e.g., liters/day)
BW	=	Body weight (kg)

When evaluating exposure to systemic toxicants, intakes are calculated by averaging intakes over the period of exposure.

### MEDIUM-SPECIFIC INTAKES

In this risk assessment, the potential exposure pathways are groundwater and air. Human exposure to contaminants in water used in residences can occur through three routes of exposure: ingestion, inhalation, and dermal absorption. People can be directly exposed to contaminants through the ingestion of tap water. Equation A-5 is used for calculating chemical intake from ingestion of drinking water.

$$I = (CW \times IR \times EF \times ED) / (BW \times AT) \quad (A-5)$$

where:

I	=	Chemical intake (mg/kg body weight-day)
CW	=	Chemical concentration in water (mg/liter)
IR	=	Ingestion rate (liters/day)
EF	=	Exposure frequency (days/year)
ED	=	Exposure duration (years)
BW	=	Body weight (kg)
AT	=	Averaging time (days)

Individuals can also be exposed to volatile organic compounds transferred from tap water to the air from showers, baths, toilets, washing machines, and cooking or through dermal contact with tap water. In this assessment, it is assumed that the intake of volatiles through inhalation will be equal to the intake estimated to occur by ingestion of drinking water. Dermal absorption is considered not likely to be a significant route of exposure. For a discussion of the basis of these assumptions, see Section 3.3.3.2 in the main report.

Equation A-6 is an equation for calculating chemical intake from inhalation of vapor phase contaminants.

$$I = (CA \times IR \times ET \times EF \times ED \times CF) / (BW \times AT) \quad (A-6)$$

where:

I	=	Chemical intake (mg/kg body weight-day)
CA	=	Chemical concentration in air ( $\mu\text{g}/\text{m}^3$ )
IR	=	Inhalation rate ( $\text{m}^3/\text{hour}$ )
ET	=	Exposure time (hours/day)
EF	=	Exposure frequency (days/years)
ED	=	Exposure duration (years)
BW	=	Body weight (kg)
AT	=	Averaging time (days)
CF	=	Conversion factor ( $10^{-3} \text{ mg}/\mu\text{g}$ )

For specific intake values used in this assessment, see Table 3-4.

## CARCINOGENIC RISK ESTIMATION

For carcinogens, risks are estimated as the incremental increase in the probability of an individual developing cancer over a lifetime as a result of exposure to a potential carcinogen. The slope factor gives the incremental risk when applied to the estimated daily chemical intakes averaged over a lifetime of exposure. This section describes the

methodology for estimating cancer risks from exposure to either a single carcinogen or multiple carcinogens.

### SINGLE CARCINOGEN

The "one-hit" equation (Equation A-7) can be used to describe excess lifetime cancer risk from exposure to one carcinogen (U.S. EPA, 1989).

$$\text{Risk} = 1 - \exp^{-(\text{SF} \times \text{CDI})} \quad (\text{A-7})$$

where:

Risk	=	Excess lifetime cancer risk as a unitless probability
SF	=	Slope factor (mg/kg-day) <sup>-1</sup>
CDI	=	Chronic daily intake averaged over a lifetime (mg/kg-day)

Where the risks are low (risk < 10<sup>-3</sup>), it can generally be assumed that the dose-response relationship will be in the linear low-dose portion of the dose-response<sup>o</sup> curve. Under this assumption, the slope factor is a constant and risk is related directly to intake. This can be described by:

$$\text{Risk} = \text{SF} \times \text{CDI} \quad (\text{A-8})$$

### MULTIPLE CARCINOGENS

Exposure situations could involve more than one carcinogen. To assess the potential for carcinogenic effects from exposure to multiple carcinogens, it is assumed that, in the absence of information on synergistic or antagonistic effects, carcinogenic risks are additive. This approach is based on EPA's Guidelines for Health Risk Assessment of Chemical Mixtures (U.S. EPA, 1986a) and EPA's Guidelines for Carcinogen Risk Assessment (U.S. EPA, 1986b).

For estimating cancer risks from exposure to multiple carcinogens from a single exposure route, the following equation is used:

$$\text{Risk}_T = \sum_{i=1}^N \text{Risk}_i \quad (\text{A-9})$$

where:

Risk <sub>T</sub>	=	Total cancer risk from route of exposure
Risk <sub>i</sub>	=	Cancer risk for the i <sup>th</sup> chemical
N	=	Number of chemicals

Risks may then be additive across exposure units if both exposures occur for the same population of receptors.

## NONCARCINOGENIC RISK ESTIMATION

### COMPARISON OF INTAKE TO REFERENCE DOSE

The potential for noncancer health effects from exposure to a contaminant is evaluated by comparing an exposure level over a specified time period with a reference dose (RfD) for a similar time period. This ratio of exposure to toxicity is called a hazard quotient and is described as follows:

$$HQ = E / RfD \quad (A-10)$$

where:

$$\begin{aligned} HQ &= \text{Noncancer hazard quotient} \\ E &= \text{Exposure level (or intake in mg/kg-day)} \\ RfD &= \text{Reference dose (mg/kg-day)} \end{aligned}$$

The results can be interpreted as follows (U.S. EPA, 1989):

$$HQ \geq 1 \quad \text{There is a potential for health effects.}$$

$$HQ < 1 \quad \text{Health effects are unlikely.}$$

### HAZARD INDEX APPROACH

For exposure situations involving more than one chemical, a "hazard index" approach can be used. This approach, which is based on EPA's Guidelines for Health Risk Assessment of Chemical Mixtures (U.S. EPA, 1986a), assumes dose additivity and sums the ratios of the daily intakes of individual chemicals to their reference doses. This sum is called the hazard index (HI).

$$HI = \sum_{i=1}^N E_i / RfD_i \quad (A-11)$$

where:

$$\begin{aligned} HI &= \text{Hazard index} \\ E_i &= \text{Daily intake of the } i^{\text{th}} \text{ chemical (mg/kg-day)} \\ RfD_i &= \text{Reference dose of the } i^{\text{th}} \text{ chemical (mg/kg-day)} \\ N &= \text{Number of Chemicals} \end{aligned}$$

When the hazard index exceeds unity, it is a numerical indicator of the transition between acceptable and unacceptable exposure levels and there might be concern for potential health effects (U.S. EPA, 1989). Any single chemical with an estimated daily intake greater than the corresponding reference dose will cause the hazard index to exceed unity.

For multiple chemical exposures, the hazard index can exceed unity even if no single chemical exposure exceeds the reference dose for that chemical. The assumption of additivity is most properly applied to chemicals that induce the same effect by the same mechanism or in the same target organ. If the hazard index is near or exceeds unity, the chemicals in the mixture may be segregated by critical effect or target organ and separated indices are derived for each effect or target organ. If any of these separate indices exceeds unity, there might be a concern for potential health effects.

### **BIBLIOGRAPHY**

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## **Appendix B**

# **PUBLIC HEALTH RISK CALCULATIONS**

### **CONTENTS**

### **TABLES**

- B-1 Excess Lifetime Cancer Risk--Ingestion and Inhalation of VOCs from Tap Water
- B-2 Noncarcinogenic Health Risk Evaluation--Ingestion and Inhalation of VOCs from Tap Water
- B-3 Excess Lifetime Cancer Risk--Inhalation of VOCs in Household Air
- B-4 Noncarcinogenic Health Risk Evaluation--Inhalation of VOCs in Household Air

<p align="center"><b>Table B-1</b>  <b>Excess Lifetime Cancer Risk--Ingestion</b>  <b>and Inhalation of VOCs from Tap Water</b></p>							
<b>Chemical</b>	<b>U.S. EPA Carcinogen Classification</b>	<b>Oral Slope Factor (mg/kg-day)<sup>-1</sup></b>	<b>Inhalation Slope Factor (mg/kg-day)<sup>-1</sup></b>	<b>Groundwater Concentration<sup>a</sup> (mg/l)</b>	<b>Lifetime Average Chemical Intake<sup>b</sup> (mg/kg-day)</b>	<b>Excess Cancer Risk Ingestion</b>	<b>Excess Cancer Risk Inhalation</b>
1,1-Dichloroethane	C	--	--	--	--	--	--
1,1-Dichloroethene	C	0.6	1.2	0.0061	0.000075	4.5 x 10 <sup>-5</sup>	9.0 x 10 <sup>-5</sup>
Freon 113	--	--	--	--	--	--	--
Toluene	--	--	--	--	--	--	--
1,1,1-Trichloroethane	--	--	--	--	--	--	--
<b>Total Risk</b>						<b>5 x 10<sup>-5</sup></b>	<b>9 x 10<sup>-5</sup></b>
<p><sup>a</sup>95 percent upper confidence limit on mean concentration (Table 3-3).  <sup>b</sup>Lifetime Average Daily Intake is the same for both ingestion and inhalation routes. Exposure assumptions used are for an adult (Table 3-4).</p>							



Table B-2 Noncarcinogenic Health Risk Evaluation--Ingestion and Inhalation of VOCs from Tap Water						
Chemical	Oral Reference Dose (mg/kg-day)	Inhalation Reference Dose (mg/kg-day)	Groundwater Concentration <sup>a</sup> (mg/l)	Daily Intake <sup>b</sup> (mg/kg-day)	Hazard Quotient Ingestion	Hazard Quotient Inhalation
1,1-Dichloroethane	0.1	0.1	0.0011	0.00011	0.0011	0.0011
1,1-Dichloroethene	0.009	0.009 <sup>c</sup>	0.0061	0.00061	0.068	0.068
Freon 113	30	30 <sup>c</sup>	0.00063	0.000063	2.1 x 10 <sup>-6</sup>	2.1 x 10 <sup>-6</sup>
Toluene	0.3	0.57	0.0025	0.00025	0.00083	0.00044
1,1,1-Trichloroethane	0.09	0.3	0.0029	0.00029	0.0032	0.0010
Total Risk					0.07	0.07

<sup>a</sup>95 percent upper confidence limit on mean concentration (Table 3-3).

<sup>b</sup>Daily Intake is the same for both ingestion and inhalation routes. Exposure assumptions used are for a child (Table 3-4).

<sup>c</sup>Oral RfD has been used for chemicals with no inhalation RfD.

Table B-3 Excess Lifetime Cancer Risk--Inhalation of VOCs in Household Air						
Chemical	U.S. EPA Carcinogen Classification	Inhalation Slope Factor (mg/kg-day) <sup>-1</sup>	Air Concentration <sup>a</sup> (µg/l)	Lifetime Average Chemical Intake <sup>b</sup> (mg/kg-day)	Excess Cancer Risk Inhalation	
Acetone	--	--	--	--	--	
1,1-Dichloroethane	C	--	--	--	--	
1,2-Dichloroethane	B2	0.091	5.9 x 10 <sup>-7</sup>	7.2 x 10 <sup>-8</sup>	6.6 x 10 <sup>-9</sup>	
1,1-Dichloroethene	C	1.2	5.8 x 10 <sup>-5</sup>	7.1 x 10 <sup>-6</sup>	8.5 x 10 <sup>-6</sup>	
Freon 113	--	--	--	--	--	
Tetrachloro-ethene	B2	0.0018	4.0 x 10 <sup>-8</sup>	4.9 x 10 <sup>-9</sup>	8.8 x 10 <sup>-12</sup>	
Toluene	--	--	--	--	--	
1,1,1-Trichloroethane	--	--	--	--	--	
1,1,2-Trichloroethane	C	0.057	2.5 x 10 <sup>-6</sup>	3.1 x 10 <sup>-7</sup>	1.7 x 10 <sup>-8</sup>	
Trichloroethene	B2	0.017	7.5 x 10 <sup>-8</sup>	9.2 x 10 <sup>-9</sup>	1.6 x 10 <sup>-10</sup>	
Total Risk						9 x 10 <sup>-6</sup>

<sup>a</sup>Maximum concentrations listed in Table 2-8.

<sup>b</sup>Exposure assumptions used are for an adult (Table 3-4).

<b>Table B-4</b> <b>Noncarcinogenic Health Risk Evaluation--Inhalation</b> <b>of VOCs in Household Air</b>				
<b>Chemical</b>	<b>Inhalation Reference Dose (mg/kg-day)</b>	<b>Air Concentration<sup>a</sup> (µg/l)</b>	<b>Daily Intake<sup>b</sup> (mg/kg-day)</b>	<b>Hazard Quotient Inhalation</b>
Acetone	0.1 <sup>c</sup>	$4.0 \times 10^{-7}$	$1.1 \times 10^{-7}$	$1.1 \times 10^{-6}$
1,1-Dichloroethane	0.1	$9.9 \times 10^{-6}$	$2.8 \times 10^{-6}$	$2.8 \times 10^{-5}$
1,2-Dichloroethane	--	$5.9 \times 10^{-7}$	--	--
1,1-Dichloroethene	0.009 <sup>c</sup>	$5.8 \times 10^{-5}$	$1.4 \times 10^{-5}$	$1.6 \times 10^{-3}$
Freon 113	30 <sup>c</sup>	$6.5 \times 10^{-7}$	$1.9 \times 10^{-7}$	$6.2 \times 10^{-9}$
Tetrachloro-ethene	0.01 <sup>c</sup>	$4.0 \times 10^{-8}$	$1.1 \times 10^{-8}$	$1.1 \times 10^{-6}$
Toluene	0.57	$4.7 \times 10^{-7}$	$1.3 \times 10^{-7}$	$2.3 \times 10^{-7}$
1,1,1-Trichloroethane	0.3	$4.5 \times 10^{-6}$	$1.3 \times 10^{-6}$	$4.3 \times 10^{-6}$
1,1,2-Trichloroethane	0.004 <sup>c</sup>	$2.5 \times 10^{-6}$	$7.1 \times 10^{-7}$	$1.9 \times 10^{-4}$
Trichloroethene	--	$7.5 \times 10^{-8}$	--	--
<b>Total Risk</b>				<b>0.002</b>
<sup>a</sup> Maximum concentrations from Table 2-8. <sup>b</sup> Exposure assumptions used are for an adult (Table 3-4). <sup>c</sup> Oral RfD has been used for chemicals with no inhalation RfD.				

## **Appendix C**

# **ECOLOGICAL ASSESSMENT**

Appendix C has been divided into two sections. Appendix C-1, Habitats and Species in the Site Vicinity contains information provided by U.S. EPA (1989) concerning potentially exposed species in the vicinity of the Sola Optical Site. Appendix C-2, Water Quality Criteria and Bioconcentration of VOCs in Aquatic Organisms, contains additional data concerning federal environmental standards and the bioaccumulation of VOCs in aquatic organisms provided by CH2M HILL.

## **Appendix C-1**

# **HABITATS AND SPECIES IN THE SITE VICINITY**

### **INTRODUCTION**

Optical lenses have been manufactured since 1978 at the Sola Optical site located in Petaluma, California (Figure C-1). In 1985, contamination was detected in soils and groundwater near the 35-acre site, and six on-site underground storage tanks were removed (U.S. EPA 1987).

The depth to groundwater at the site ranged from 9 to 15 feet below ground surface (Levine-Fricke, 1990). Groundwater flow is believed to be the southwest and west towards Adobe Creek and the Petaluma River (Levine-Fricke, 1987). Adobe Creek lies 0.3 miles (460 meters) west of the site and flows into the Petaluma River, approximately 1 mile (1.6 km) from the site. The Petaluma River empties into San Pablo Bay, 8 miles (13 km) from the confluence with Adobe Creek.

A contaminant migratory pathway at the National Oceanic and Atmospheric Administration (NOAA) trust resources is via groundwater flow to the Adobe Creek.

### **SITE-RELATED CONTAMINATION**

Soil borings and groundwater sampling from on-site wells indicated that the soils and shallow subsurface water (less than 12 meters below the surface) were contaminated with VOCs (see Tables 2-3 and 2-6). Contaminants were not detected in upgradient wells. Contaminants found during the 1990 annual and semiannual sampling of Levine-Fricke wells both offsite and downgradient included 1,1-dichloroethene (1,1-DCE) (maximum of 0.022 mg/l), 1,1-dichloroethane (1,1 DCA) (maximum of 0.005 mg/l), 1,1,1-trichloroethane (1,1,1-TCA) (maximum of 0.012 mg/l), Freon 113 (maximum of 0.004 mg/l), and toluene (maximum of 0.003 mg/l). A review of the groundwater monitoring data from 1986 to 1990 shows levels of 1,1-DCE at a maximum of 3.3 mg/l, 1,1-DCA at a maximum of 1.7 mg/l, 1,1,1-TCA at a maximum of 3.3 mg/l, Freon 113 at a maximum of 0.01 mg/l and toluene at a maximum of 0.017 mg/l. There is no reported evidence of surface water contamination at this site.

### **TRUST HABITATS AND SPECIES IN SITE VICINITY**

Adobe Creek is continuously flowing, low-gradient tidal creek. There are no known resources of concern to NOAA in Adobe Creek (Enig, 1989). However, a local high school has begun artificial propagation of steelhead along Adobe Creek, with assistance from the California Department of Fish and Game. This creek could become of interest to NOAA if the program is successful.

Habitats presently of concern to NOAA include the Petaluma River (Table 4-1). The Petaluma River is a low-salinity, tidal river near the Sola Optical site. The Petaluma Marsh State Wetland Area extends along the west bank of the Petaluma River from Adobe Creek to the river's entrance into San Pablo Bay (Enig, 1989). Twenty mating pairs of steelhead trout use the Petaluma River headwaters for spawning. No other salmonids use the Petaluma River drainage basin for spawning; loss of spawning habitat and poor water quality limits salmonid production for this system (Rugg, 1989).

<b>Table C-1</b> <b>NOAA Trust Resource Use of the Petaluma River and</b> <b>Lower Marshland Estuary</b> <b>(USFWS, 1981)</b>						
<b>Species</b>	<b>Nursery Area</b>	<b>Spawning Area</b>	<b>Adult Area</b>	<b>Migration Corridor</b>	<b>Recreational Fishery</b>	<b>Commercial Fishery</b>
<b>Invertebrates</b>						
bay shrimp	X	X	X		X	X
Dungeness crab	X	X	X		X	
<b>Fish</b>						
chinook salmon			X	X		
coho salmon			X	X		
green sturgeon			X	X		
starry flounder	X		X			
steelhead	X	X	X	X		
striped bass	X		X			

Dungeness crab, starry flounder, striped bass, and bay shrimp use the lower Petaluma River estuary and associated wetlands for juvenile development. Extensive channels reach into the marshlands, providing access to the productive brackish waters. Adult chinook and coho salmon use the lower estuary as foraging grounds as they migrate to the Sacramento River. Green sturgeon, though not common, have been reported in the Petaluma River. Green Sturgeon, like chinook and coho salmon, use the lower estuary for foraging. There is a bay shrimp fishery in northern San Pablo Bay near the Petaluma River estuary. Dungeness crab, starry flounder, striped bass, and sturgeon are harvested recreationally in the lower Petaluma River estuary (Rugg, 1989).

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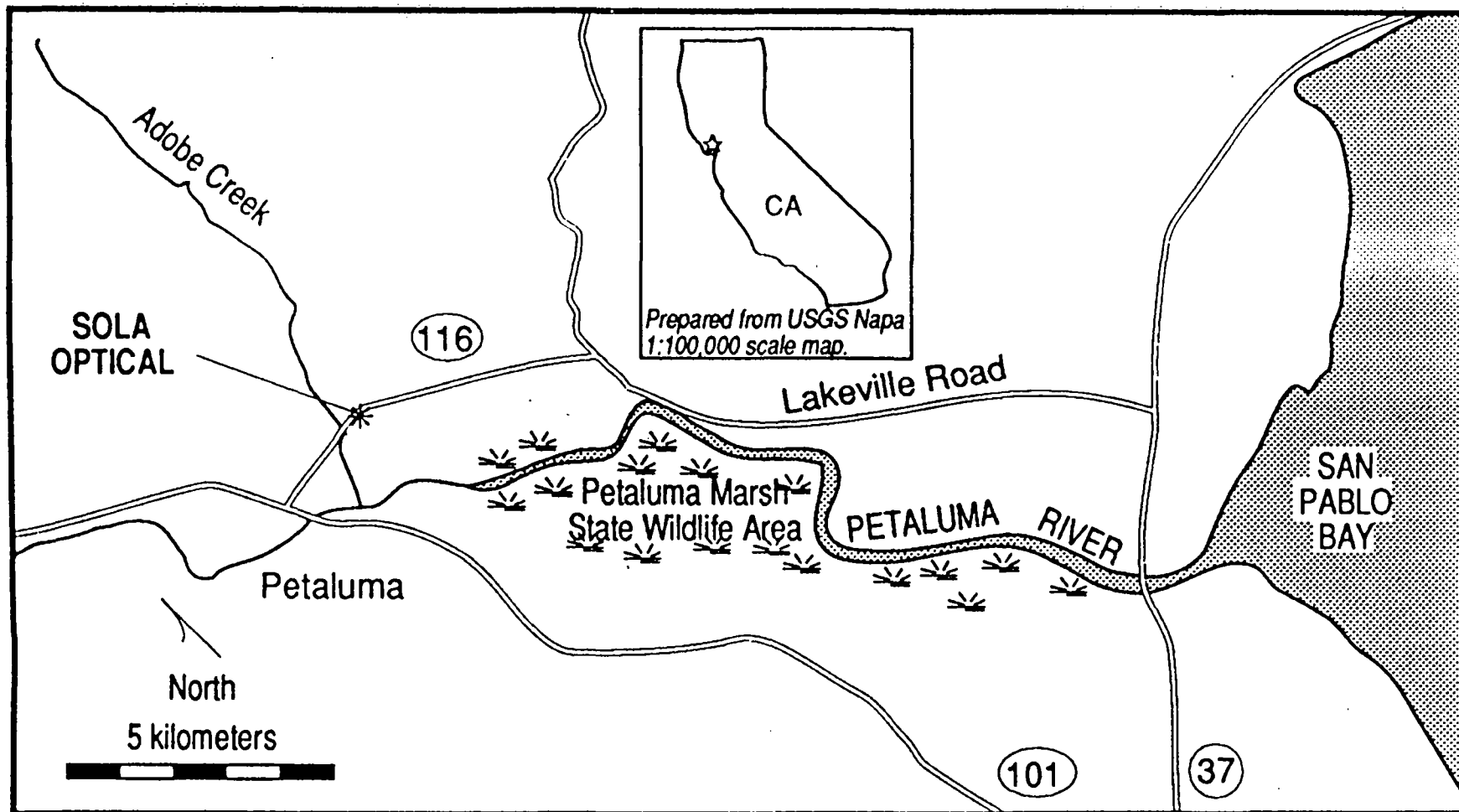


FIGURE C1-1  
THE SOLA OPTICAL SITE IN  
PETALUMA, CALIFORNIA

CHM HILL



## Appendix C-2

# WATER QUALITY CRITERIA AND BIOCONCENTRATION OF VOCs IN AQUATIC ORGANISMS

### WATER QUALITY CRITERIA

The U.S. EPA has set National Ambient Water Quality Criteria (WQC) for the protection of freshwater and saltwater aquatic life from acute and chronic toxicity under Section 304 of the Clean Water Act (33 U.S.C. 1314). These WQC are not enforceable standards but provide contaminant concentrations which should be adequate to protect most aquatic life. Of the five chemicals detected in the Levine-Fricke 1990 annual and semiannual groundwater sampling events (see Section 2.0), acute WQC for freshwater aquatic life have been developed for 1,1-DCE (11.6 mg/l), toluene (17 mg/l), and 1,1,1-TCA (18 mg/l). Chronic freshwater WQC have not been set for any of the five chemicals. Acute WQC for saltwater aquatic life have been developed for 1,1-DCE (224 mg/l), toluene (6.3 mg/l), and 1,1,1-TCA (31.2 mg/l). Only toluene has a chronic WQC level for saltwater species, 5.0 mg/l. At their maximum groundwater concentrations, all three chemicals were detected at the site below their corresponding acute and chronic water quality criteria.

### BIOCONCENTRATION IN AQUATIC SPECIES

Bioconcentration factors (BCF) are an indication of the tendency for a contaminant in water to accumulate in the tissue of aquatic organisms. BCFs are defined as follows (Lyman et al., 1990):

$$\text{BCF} = \frac{\text{Concentration of chemical at equilibrium in organism (wet weight)}}{\text{Mean concentration of chemical in water}}$$

BCFs for four of the five chemicals were available from U.S. EPA (1989a). The log BCF for 1,1-DCA is 1.13, 1.39 for 1,1-DCE, 1.57 for toluene, and 0.95 for 1,1,1-TCA. According to U.S. EPA (1989b), low molecular weight volatile organic compounds do not bioaccumulate in aquatic organisms to a great extent. The BCF for these chemicals can also be compared to a known problematic accumulator, such as DDT, to evaluate the potential for the chemical to be taken up and stored in the aquatic organism (Lyman et al., 1990). According to U.S. EPA (1989a), the log BCF for DDT is 4.97, over 2,000 times higher than the BCF for chemicals detected at this site.

### SUMMARY

Chemicals detected at the site are present in concentrations below their corresponding water quality criteria for the protection of aquatic life. Due to the distance between the site and the Adobe Creek and Petaluma River, these concentrations would be

conservative estimates of the exposure to aquatic organisms in these locations. In addition, bioconcentration factors for the detected chemicals are well below those of chemicals, such as DDT, which are known to be taken up and stored in aquatic organisms.

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**ATTACHMENT I**



**DRAFT**



**DRAFT  
TECHNICAL MEMORANDUM  
RESULTS OF SUBSURFACE TRANSPORT MODELING  
SOLA OPTICAL USA, INC. SITE  
PETALUMA, CALIFORNIA**

**February 5, 1991  
1954.05**

**Prepared for:**

**Sola Optical USA, Inc.  
1500 Cader Lane  
Petaluma, California**



**LEVINE·FRICKE**



# LEVINE-FRICKE

CONSULTING ENGINEERS AND HYDROGEOLOGISTS

February 6, 1991

LF 1954.06

Mr. Michael M. Montgomery  
Mail Code H-7-1  
U.S. EPA Region IX  
Hazardous Waste Management Division  
Superfund Branch/Enforcement Response Section  
75 Hawthorn Street  
San Francisco, CA 94105

Subject: Preliminary Draft Results of Subsurface Transport  
Modeling, Sola Optical USA, Inc. (Sola) Site

Dear Mr. Montgomery:

Per our telephone conversation on February 4 1991, enclosed please find a preliminary draft version of a technical memorandum presenting the results of subsurface transport modeling conducted by Levine-Fricke on behalf of Sola for the Sola Site. The enclosed preliminary draft is a "working copy" of the technical memorandum. Levine-Fricke is in the process of conducting a QA/QC evaluation of the subsurface transport modeling that was conducted. Therefore, the results presented in the enclosed preliminary draft are subject to change per the results of the QA/QC evaluation.

Sincerely,

Scott Seyfried  
Project Scientist

cc: Mark Adams  
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DRAFT

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DRAFT

D R A F T

LEVINE-FRICKE

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DRAFT



February 5, 1991

LF 1954.05

## TECHNICAL MEMORANDUM

RESULTS OF SUBSURFACE TRANSPORT MODELING  
SOLA OPTICAL USA, INC., SITE  
PETALUMA, CALIFORNIA

## 1.0 INTRODUCTION

This technical memorandum has been prepared on behalf of Sola Optical USA, Inc., a division of Pilkington Visioncare, Inc. (referred to as "Sola") at the request of the U.S. Environmental Protection Agency, Region IX (EPA) as part of Remedial Investigation/Feasibility Study (RI/FS) activities at the Sola Site in Petaluma, California ("the Site"). This technical memorandum presents the results of modeling conducted by Levine-Fricke to assess the potential impacts of chemicals detected in vadose-zone soils on underlying shallow ground water at the Site.

## Background

During April 1990, vadose-zone soils were sampled and analyzed and a soil-gas survey was conducted in the vicinity of six former underground storage tanks at the Site as part of RI activities. Results of the soil sampling and analysis are included in the document entitled "Remedial Investigation Report, Sola Optical USA, Inc., Petaluma, California," dated and submitted to the EPA on December 3, 1990 (the RI Report). Analytical results of soil samples revealed concentrations of chlorinated volatile organic compounds (VOCs) ranging from below laboratory detection limits to 0.160 parts per million (ppm) of 1,1-dichloroethane (1,1-DCA). Toluene, 2-butanone, and 4-methyl-2-pentanone were also detected, with a maximum concentration of 0.270 ppm for 4-methyl-2-pentanone. Acetone was detected in two soil samples at concentrations of 0.11 ppm and 4.6 ppm, respectively.

A comparison of VOC concentrations in ground water and overlying soils, conducted as part of the RI Report, indicated that vadose-zone soils in the vicinity of the location of the former storage tanks do not constitute a significant source of VOCs to the underlying shallow ground water at the Site. The RI Report concluded that, with the exception of acetone, VOC concentrations detected in soil and soil gas appear to result

from volatilization from the underlying shallow ground water and/or upward migration of VOCs in shallow ground water via capillary pressure gradients.

EPA's subcontractor (CH<sub>2</sub>M Hill) requested that Levine-Fricke conduct subsurface transport modeling to confirm the findings of the RI Report and to further assess the potential impacts of VOCs in soils in the vicinity of the former tanks on shallow ground-water quality at the Site. This request was made during a meeting between representatives of Sola, Levine-Fricke, the EPA, and CH<sub>2</sub>M Hill on November 9, 1990. CH<sub>2</sub>M Hill recommended that Levine-Fricke use the VLEACH soil model to conduct the vadose-zone modeling. Levine-Fricke compared results of transport modeling using the VLEACH model (developed by CH<sub>2</sub>M Hill for use at an EPA Superfund site) with those of a second vadose-zone model, SESOIL (Bonazountas and Wagner, 1984; Hetrick et al., 1989; and GSC, 1989), by applying them to similar scenarios. This comparison showed that the VLEACH model produced similar results to the SESOIL model. The primary difference between the two models is that the VLEACH model is not capable of simulating the potential effects of biodegradation on transport.

VLEACH and a ground-water mixing cell model were then used to assess the potential impacts of VOCs in soils at the Site on ground-water quality. The results of this analysis are presented below.

## 2.0 ESTIMATED GROUND-WATER CONCENTRATIONS FOR CHEMICALS OF CONCERN

This section presents estimates of the potential ground-water concentrations for chemicals of concern that may result from leaching of VOCs in source area soils.

The computer program VLEACH, developed by CH<sub>2</sub>M Hill, was used to calculate the mass flux of each chemical through the vadose zone and into ground water. A simple mixing cell model was used to estimate the ground-water concentrations of each chemical as a result of the VLEACH simulated chemical loading from overlying soils. The mixing cell model uses the control volume approach to ground-water transport problems, as discussed further in Section 2.4.

## 2.1 Chemicals of Concern

Concentrations of the VOCs detected in soil samples from borings in the source area are shown in both Table 6 and Figure 10 of the RI Report (Levine-Fricke, 1990). The results of the soil-gas survey are presented in Figure 8 of the RI Report.

Because 1,1-DCA and 1,1-dichloroethene (1,1-DCE) are the most prevalent VOCs detected in the source area soils and underlying ground water, and because these two chemicals also have the highest risk factors for ingestion, the leachate flux and resultant ground-water concentrations were simulated for these two chemicals. Other VOCs detected in soils at the Site were detected at much lower concentrations, and/or their health risk factors are so low that they are considered to pose insignificant potential risk compared to the potential risk posed by the 1,1-DCA and 1,1-DCE detected in soils at the Site.

### Assumed Lateral Extent of VOCs in Soil

The concentrations of 1,1-DCA and 1,1-DCE in soil samples, and their associated areas off the Site, are listed in Table 1. The area associated with each soil boring (or soil-gas survey point) was assumed to extend from the soil borings (or soil-gas survey points) where the chemical was detected to points halfway between these borings and the perimeter borings where the chemical was not detected. Given the relatively wide spacing of the soil borings (and soil-gas survey points) (about 20 to 30 feet), this assumption resulted in a conservatively large area for affected soils.

### Assumed Vertical Distribution of VOCs in Soil

The assumed soil concentration profiles associated with the boring and soil-gas survey locations are shown in Table 3. The soil-gas survey results for samples collected at shallow depths indicated that surface soils (up to 2 feet in depth) at these areas did not contain concentrations of VOCs above detection limits. At each sampling point, the soil concentration was assumed to be zero at the surface and to increase linearly from the surface to the depth at which VOCs were detected. The soil concentration below that depth was assumed to be constant and equal to the concentration detected in the deepest soil sample, from the deepest sample location to the water table (assumed to lie at 15 feet below surface).

### 2.1.1 Extent in Soil and Properties of 1,1-DCA

Table 1 lists the concentrations of 1,1-DCA detected at soil borings SB-4, SB-5, SB-6 and soil-gas survey locations SG-2, SG-30, SG-33, SG-35 and SG-40. The total soil concentration of 1,1-DCA at soil-gas survey points was calculated from the concentrations of 1,1-DCA detected in the soil gas (soil-gas survey results of April 1990) using partitioning equations (see Sections 2.1.1.2 and 2.1.2.3 of the RI Report). The simulated source areas for 1,1-DCA are shown in Figure 1.

The following chemical and physical properties were used for 1,1-DCA (Montgomery and Welkom, 1989): an organic carbon distribution coefficient ( $K_{oc}$ ) of 0.030 m<sup>3</sup>/Kg (30 ml/g), dimensionless Henry's Law constant of 0.178, and an aqueous solubility of 5.500 Kg/m<sup>3</sup> (5,500 mg/l); and an air diffusion coefficient of 0.78564 m<sup>2</sup>/day taken from Shen (1981) (see Table 2). All parameters correspond to a temperature of 20 degrees Celsius.

### 2.1.2 Extent in Soil and Properties of 1,1-DCE

Table 1 lists the concentrations of 1,1-DCE detected at soil borings SB-5 and SB-6 and soil-gas survey locations SG-40, SG-30, SG-33, and SG-35. The total soil concentration of 1,1-DCE at soil-gas survey points was calculated from the concentrations of 1,1-DCE detected in the soil gas (soil-gas survey results of April 1990) using partitioning equations (see Sections 2.1.1.2 and 2.1.2.3 of the RI Report). The areas associated with the above-mentioned soil-gas survey points and soil borings are shown in Figure 1.

The following chemical and physical properties were used for 1,1-DCE (Montgomery and Welkom, 1989):  $K_{oc}$  value of 0.065 m<sup>3</sup>/Kg (65 ml/g); dimensionless Henry's Law constant of 0.857; an aqueous solubility of 2.250 Kg/m<sup>3</sup> (2250 mg/l); and an air diffusion coefficient of 0.68316 m<sup>2</sup>/day taken from Shen (1981). All parameters correspond to 20 degrees Celsius.

## **2.2 Characteristics of Source Area Soils**

Based on field observations, the following physical properties were assumed for source area soils at the Site: a bulk density of 1,320 Kg/m<sup>3</sup> (1.32 g/cm<sup>3</sup>); a total porosity of 0.5; a volumetric water content of 0.3; and an organic carbon content of 0.02 (2 percent).

### 2.3 Simulation of Mass Loading from Soil to Underlying Ground Water Using VLEACH

The one-dimensional finite difference computer model VLEACH, developed by CH<sub>2</sub>M Hill, was used to simulate the transport of chemicals from vadose-zone soils to the water table. VLEACH simulates aqueous advection and gaseous diffusion processes. For each space and time step, the model equilibrates chemical concentrations between the aqueous, gaseous, and adsorbed phases using linear partitioning equations. VLEACH is not capable of representing chemical or biological degradation. Thus, the effects of degradation in the vadose zone, which would further reduce chemical concentrations, were not considered.

#### 2.3.1 Parameters Used in the VLEACH Simulations

The parameters used in VLEACH are listed in Tables 2 and 3.

VLEACH simulations were run with a one-year time step for a total simulation time of 80 years. Six polygons were used to represent the source areas for 1,1-DCA in soils and four polygons were used for 1,1-DCE to represent the simulated source areas (see Table 3). Fifteen one-foot thick cells were used to represent vadose-zone soils to a total depth of 4.57 m (15 feet). The ground-water recharge rate used was conservatively estimated to be 0.5 inches per year (0.0417 feet/year) corresponding to an unpaved surface scenario. The actual net recharge to ground water is probably lower than the calculated rate because low-permeability clays are present in shallow soils at the Site and the majority of the surface is paved. The chemical concentrations in infiltrating water and ambient air were assumed to be zero. The water table was assumed to be impermeable to gaseous diffusion, and it was assumed that the chemicals of concern do not degrade in the vadose zone.

#### 2.3.2 VLEACH Simulation Results

The VLEACH output files are given in Appendix A.

The VLEACH simulation results provide estimates of the expected mass-loading rate from soils to the underlying ground water. These estimates are considered to be conservatively high because the recharge rate corresponding to a paved area is substantially lower than 0.5 inches/year, and because the effects of biodegradation, which would further reduce VOC concentrations, were not considered in the simulations.

The total chemical mass loading rates to ground water for input to the mixing cell model were calculated based on the total mass loading to ground water from the source area soils provided by the VLEACH output (Appendix A). The chemical mass was then mixed into the underlying ground water using the mixing cell model to assess the impact on ground-water quality, as described below.

#### 2.4 Simulation of Ground-Water Concentrations Using a Simple Mixing Model

A simple mixing cell model was used to estimate chemical concentrations in ground water beneath the source area over a period of 80 years. For the purpose of applying the ground-water cell model, a composite rectangular area was defined as shown on Figure 2. This composite area is equal to the sum of the polygon areas shown in Figure 1. The mixing cell volume was calculated by multiplying the surface area shown in Figure 2 of the source by the saturated thickness and the porosity of the saturated shallow-zone sediments. This model assumes that the mass loading from the vadose zone mixes completely with the ground water contained in the saturated thickness of shallow-zone sediments beneath the source area and is continuously "flushed" with clean, upgradient ground water.

A FORTRAN program was written to efficiently perform computations associated with the mixing cell model over time. The FORTRAN program simulated the following steps:

Step 1: The volume of the mixing cell was calculated by multiplying the area of the source by the saturated thickness of the shallow-zone sediments and the porosity of the formation:

$$\text{Vol} = \text{Width} * \text{Length} * b * \text{Pt}$$

where:

Vol = volume of the mixing cell ( $\text{m}^3$ )  
 Width = crossgradient width of the source area (m)  
 Length = downgradient length of the source area (m)  
 b = saturated thickness of sediments (m)  
 Pt = total porosity (dimensionless)

The ground-water flow rate was calculated using Darcy's Law:

$$Q = (K * i) * \text{Width} * b$$

where:

Q = ground-water flow rate ( $\text{m}^3/\text{year}$ )  
 K = hydraulic conductivity of the sediments ( $\text{m}/\text{year}$ )  
 i = hydraulic gradient in the vicinity of source area  
 (dimensionless)

Step 2: The initial concentration of the chemical in the cell was calculated using the mass loading rate into the shallow-zone sediments during the first year:

$$C(1) = \text{Massin}(1)/\text{Vol}$$

where:

C(1) = ground-water concentration during the first year  
 ( $\text{kg}/\text{m}^3$ )

Massin(1) = mass loading to the shallow-zone sediment interval during the first year (kg)

Step 3: The mass leaving the mixing cell during each time step, I, is:

$$\text{Massout} (I) = C (I-1) * Q$$

where:

Massout (I) = the mass leaving the mixing cell during year I (Kg)

C(I-1) = concentration in the mixing cell during the previous year (I-1) ( $\text{Kg}/\text{m}^3$ )

Step 4: The new mixing cell concentration is calculated using:

$$C(I) = (\text{Massin}(I) - \text{Massout}(I)) / \text{Vol} + C(I-1)$$

Step 5: Steps 3 and 4 are repeated for successive time steps until the concentration in the mixing cell is calculated for all the years required in the simulation.

#### 2.4.1 Characteristics of the Shallow-Zone Sediments (Underlying the Source Area)

For the purpose of evaluating water-quality impacts to shallow ground water underlying the source area, chemical mixing in the saturated interval from the water table (approximately 15 feet deep) to a depth of approximately 50 ft was simulated. The shallow ground-water depth interval used in the mixing calculations presented here is much shallower than potential water-supply sediment intervals which are typically present in this area at depths greater than 200 feet.

The total porosity in the saturated zone under the source area was assumed to be 0.4. Analysis of the hydraulic test conducted at well E-8 resulted in an estimated transmissivity of 869 gpd/ft or 116 ft<sup>2</sup>/day (Table 3 of the RI Report) for shallow-zone sediments in this vicinity. This transmissivity value is considered representative of the 35-foot thick saturated interval; however, to allow for heterogeneities and the possibility that the transmissivity is lower directly under the source area, this transmissivity value was divided by two for the conservative mixing model calculations. Based on this conservatively low transmissivity value, an average hydraulic conductivity for the 35-foot thick interval is 185 m/yr or  $5.9 \times 10^{-4}$  cm/sec. The hydraulic gradient in the vicinity of the assumed source area was estimated to be approximately 0.012 m/m based on ground-water elevation data collected on July 31, 1990 for shallow- and intermediate-zone wells.

#### 2.4.2 The Mixing Cell Model Input Parameters

Input parameters used in the mixing cell model are tabulated in Table 4, and the computer output are provided in Appendix B.

Since VLEACH simulates mass loading to ground water in one-year time steps, the mixing cell model was run using annual mass loading inputs. Both the soil and ground-water transport simulations (VLEACH and mixing cell model) were conducted for 80 years. The ground-water impact results from VLEACH and the mixing cell model were printed for annual increments.

The shallow and intermediate ground-water sediment interval were assumed to be 11 m (35 ft) thick near the assumed source area (based on lithologic data from nearby wells) and infinite in lateral extent. The mixing cell dimensions were taken as 24 m (80 ft), 12 m (39 ft) and 11 m (35 ft) for the crossgradient width, downgradient length, and depth, respectively. These dimensions represent a composite of the



soil source area polygons (Figure 2). Multiplying this total volume by the porosity of the saturated sediments (0.4) resulted in a calculated volume of 1,288 m<sup>3</sup>.

Based on the sediment characteristics provided in Section 2.4.1 (hydraulic conductivity of 185 m/year and hydraulic gradient of 0.012), the ground-water flow rate into and out of the cell was calculated to be 595 m<sup>3</sup>/year.

#### 2.4.3 Results of Mixing Cell Model Simulations

The mixing cell model simulation results are presented in Appendix B. Chemical concentrations were calculated for points beneath the assumed source area. Table 5 lists the simulated maximum ground-water concentrations at the source area. For comparison purposes, the Maximum Contaminant Levels for drinking water (MCLs) for 1,1-DCA and 1,1-DCE are also included in Table 5.

##### 2.4.3.1 Simulated Results for 1,1-DCA

The simulated ground-water concentration of 1,1-DCA beneath the assumed source area increased with time, reaching a maximum of 0.41 ppb during the 7th year. Simulated concentrations of 1,1-DCA in ground water underneath the source area decreased (after the 7th year) to 0.16 ppb for the 80th year of the simulation. These concentrations are significantly lower than the MCL of 5 ppb for this chemical.

##### 2.4.3.2 Simulated Results for 1,1-DCE

Simulated ground-water concentration of 1,1-DCE beneath the assumed source area increased with time, reaching a maximum of 0.70 ppb during the 6th year. Simulated concentrations of 1,1-DCA in ground water underneath the source area decreased (after the 6th year) to 0.10 ppb in the 80th year of the simulation. These concentrations are significantly lower than the MCL of 6 ppb for this chemical.

## 2.5 Discussion of Simulation Results

Simulated maximum concentrations of 1,1-DCA and 1,1-DCE in shallow ground water predicted to occur at the source area are significantly below MCLs for these chemicals (5 ppb and 6 ppb, respectively). Considering the neglected effects of dispersion, retardation, and biodegradation, concentrations within the water-bearing interval would be even lower than the calculated values presented herein. These modeling results indicate that soils at the Site do not represent a significant source of VOCs to underlying ground water.

The simulated concentrations presented in Table 4 are considered to be conservatively high due to the conservative assumptions used in the VLEACH and mixing cell modeling.

10-10-91

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TABLE 1

CONCENTRATIONS OF 1,1-DCA AND 1,1-DCE DETECTED IN SOILS  
IN THE SOURCE AREA AND THE AREA ASSOCIATED WITH  
EACH SOIL BORING OR SOIL-GAS SURVEY LOCATION

Sola Optical USA, Inc.  
Petaluma, California

Soil Boring or Soil-Gas Survey Location	Associated * Polygon Area (ft <sup>2</sup> )	Depth Below Soil Surface (feet)	1,1-DCA ** Soil Concentration (ppb)	1,1-DCE ** Soil Concentration (ppb)
SG-30, SG-33, SG-35 (cluster) ***	300	8 2	13.3 2.5	31.7 <2.5
SB-6	660	8.5 6.5	16 14	<2.5 2.5
SB-5	660	8.5 4	160 20	34 <2.5
SG-40	616	7	50	1,000
SB-4	616	9.5 6.5	51 16	--- ---
SG-2	225	6	20	---

## Notes:

- \* The area associated with each chemical was assumed to extend from the soil where the chemical was detected to points halfway between these borings and the perimeter soil borings where the chemical was not detected.
- \*\* Concentration detected in soil samples collected during April 1990, and detected in soil gas during soil-gas survey in April 1990.
- \*\*\* Average of the concentrations found at these three soil-gas survey locations. Soil concentrations were calculated from the soil-gas data using soil-gas/soil partitioning equations (see Sections 2.1.22 and 2.1.2.3 of the RI Report).

TABLE 2

## PARAMETERS USED IN VLEACH

Sola Optical USA, Inc.  
Petaluma, California

PARAMETER	VALUE FOR 1,1-DCA	VALUE FOR 1,1-DCE	DESCRIPTION
DELT:	1	1	Computational timestep (years)
STIME:	80	80	Total length of simulation (years)
PTIME:	1	1	Interval at which ground-water impact and mass balance results are printed to .OUT file (years)
PRTIME:	1	1	Interval at which vertical-concentration profile results are printed to .PRF file (years)
KOC:	30	65	Organic carbon distribution coefficient (ml/g)
KH:	.178	.857	Henry's constant (dimensionless)
CMAX:	5500	2250	Aqueous solubility (mg/l)
DAIR:	.78564	.68316	Free air diffusion coefficient (m2/day)
AREA:	*	*	Area of polygon (sq. ft.)
DELZ:	1	1	Vertical cell spacing (ft.)
Q:	0.0417	0.0417	Ground-water recharge rate (ft./yr.)
RHOB:	1.32	1.32	Dry bulk density of soil (g/cc)
POR:	0.5	0.5	Porosity (dimensionless)
THETA:	0.3	0.3	Volumetric water content (dimensionless)
FOC:	0.02	0.02	Soil organic carbon content (dimensionless)
CINF:	0	0	Concentration of chemical in recharge water (mg/l)
CATM:	0	0	Concentration of chemical in atmosphere above polygon (mg/l)
CGW:	-1	-1	Determines lower boundary condition for gas diffusion. If CGW is negative, water table is impermeable to gas diffusion. If CGW is non-negative, it indicates the (fixed) concentration of chemical below the water table, affecting gas diffusion only (mg/l)
J1:	*	*	Top cell described by couplet
J2:	*	*	Bottom cell described by couplet
XCON:	*	*	Initial total mass of chemical in each of cells J1 through J2 (ppb)

## Notes:

Parameters are listed in the order of appearance in Vleach input file: BATCH.INP

\* - Refer to Table 3 for polygon areas and associated concentration profile.

TABLE 3

POLYGON AREAS AND ASSOCIATED CONCENTRATION PROFILES  
FOR 1,1-DCA AND 1,1-DCE IN SOILS USED IN VLEACH MODELING

Sola Optical USA, Inc.  
Petaluma, California

Polygon	Area (sq ft)	Layer Number	Initial Total Concentration of Chemical in the Layer (ppb)
<u>1,1-DCA</u>			
Polygon 1: SG-30, SG-33 and SG-35 (cluster)	300	1	1.3
		2	2.5
		3	4.3
		4	6.1
		5	7.9
		6	9.7
		7	11.5
		8 - 15	13.3
Polygon 2: SB-6	660	1	3.1
		2	6.2
		3	9.3
		4	12.4
		5	14.3
		6	14.8
		7	15.3
		8	15.8
Polygon 3: SB-5	660	9 - 15	16.0
		1	5.0
		2	10.0
		3	15.0
		4	20.0
		5	48.0
		6	76.0
		7	104.0
Polygon 4: SG-40	616	8	132.0
		9 - 15	160.0
		1	7.1
		2	14.2
		3	21.3
		4	28.4
		5	35.5
		6	42.6
Polygon 5: SB-4	616	7 - 15	50.0
		1	2.5
		2	4.9
		3	7.4
		4	9.8
		5	12.3
		6	14.8
		7	21.6
Polygon 6: SG-2	225	8	33.3
		9	45.0
		10 - 15	51.0
		1	3.3
		2	6.7
		3	10.0
		4	13.3
		5	16.7
		6 - 15	20.0

TABLE 3

## POLYGON AREAS AND ASSOCIATED CONCENTRATION PROFILES USED IN VLEACH

Sola Optical USA, Inc.  
Petaluma, California

Polygon	Area (sq ft)	Layer Number	Initial Total Concentration of Chemical in the Layer (ppb)
<u>1,1-DCE</u>			
Polygon 1:	300	1	4.0
SG-30, SG-33,		2	7.9
SG-35 cluster		3	11.9
		4	15.8
		5	19.8
		6	23.7
		7	27.7
		8 - 15	31.7
Polygon 2:	660	1	1.1
SB-6		2	2.2
		3	3.3
		4	4.4
		5	5.0
		6	3.3
		7	2.5
		8	2.5
		9 - 15	2.5
Polygon 3:	660	1	0.6
SB-5		2	1.3
		3	1.9
		4	2.5
		5	8.2
		6	14.0
		7	19.7
		8	25.4
		9 - 15	34.0
Polygon 4:	616	1	142.9
SG-40		2	285.7
		3	428.6
		4	571.4
		5	714.3
		6	857.1
		7 - 15	1000.0

TABLE 4

## PARAMETERS USED IN THE MIXING CELL MODEL

Sola Optical USA, Inc.  
Petaluma, California

Parameter	Explanation	Value
Pt	total porosity in the saturated zone	0.4 (-)
Width	crossgradient width of the cell	24 (m)
Length	downgradient length of the cell	12 (m)
b	saturated thickness	11 (m)
K	hydraulic conductivity	185 (m/year)
i	hydraulic gradient	0.012 (-)
Q	ground-water flow rate	595 (m <sup>3</sup> /year)
VOL	volume of the water in the cell	1,288 (m <sup>3</sup> )

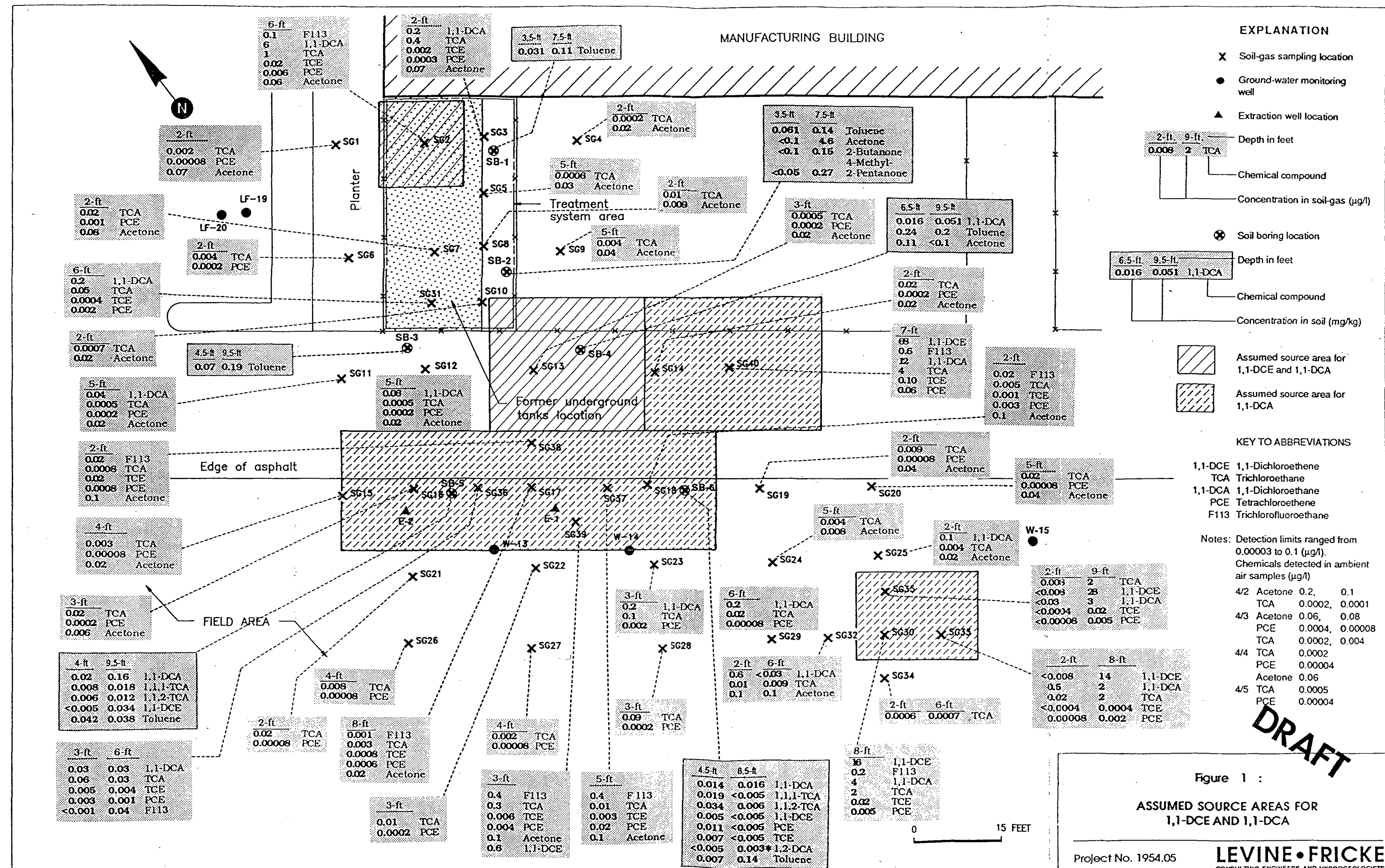


TABLE 5

RESULTS OF MIXING CELL MODEL:  
SIMULATED MAXIMUM GROUND-WATER CONCENTRATIONS  
AT THE ASSUMED SOURCE AREA

Sola Optical USA, Inc.  
Petaluma, California

Chemical	Maximum Simulated Ground-Water Concentration at the Source (ppb)	Time of Maximum Concentration (year)	Maximum Contaminant Level in Drinking Water (ppb)
1,1-DCA	0.41	7	5
1,1-DCE	0.70	6	6



MANUFACTURING BUILDING

EXPLANATION

- X Soil-gas sampling location
- Ground-water monitoring well
- ▲ Extraction well location
- 2-ft, 9-ft Depth in feet
- 0.008 2 TCA Chemical compound
- Concentration in soil-gas (µg/l)
- ⊗ Soil boring location
- 6.5-ft, 9.5-ft Depth in feet
- 0.016 0.051 1,1-DCA Chemical compound
- Concentration in soil (mg/kg)
- Assumed surface area of the mixing cell

KEY TO ABBREVIATIONS

- 1,1-DCE 1,1-Dichloroethene
- TCA Trichloroethane
- 1,1-DCA 1,1-Dichloroethane
- PCE Tetrachloroethene
- F113 Trichlorofluoroethane

Notes: Detection limits ranged from 0.00003 to 0.1 (µg/l).  
Chemicals detected in ambient air samples (µg/l)

4/2	Acetone	0.2,	0.1
	TCA	0.0002,	0.0001
4/3	Acetone	0.06,	0.08
	PCE	0.0004,	0.00008
	TCA	0.0002,	0.004
4/4	TCA	0.0002	
	PCE	0.00004	
	Acetone	0.06	
4/5	TCA	0.0005	
	PCE	0.00004	

DRAFT

Figure 2 :  
ASSUMED SURFACE AREA  
OF THE MIXING CELL

Project No. 1954.05

LEVINE • FRICKE  
CONSULTING ENGINEERS AND HYDROGEOLOGISTS

**ATTACHMENT II**

# VLEACH

## A ONE-DIMENSIONAL FINITE DIFFERENCE VADOSE ZONE LEACHING MODEL

### MODEL DESCRIPTION

#### INTRODUCTION

VLEACH is a one-dimensional finite difference model designed to simulate the leaching of a volatile, sorbed contaminant through the vadose zone. (Although the term "contaminant" is used throughout this guide, VLEACH could be used to model the transport of any non-reactive chemical that displays linear partitioning behavior). It models four main processes: liquid-phase advection, solid-phase sorption, vapor-phase diffusion, and three-phase equilibration. In its current version, VLEACH is subject to a number of major assumptions:

- Contaminant partitioning between phases follow linear relationships, i.e., both  $K_D$  and  $K_H$  are constants.
- The three phases present (liquid, vapor, sorbed) are in a state of equilibrium in each cell.
- The moisture content profile within the vadose zone is constant, i.e., the vadose zone is in a steady state with respect to water.
- Liquid-phase dispersion is neglected.
- No "free product" is present.
- The contaminant is not subject to in situ production or degradation.
- The vadose zone soil within a particular model polygon is completely homogeneous, and behaves as a uniform porous medium, with no preferential pathways to flow.
- Volatilization from the soil surface is either completely unimpeded or completely restricted.

Some of these limitations may be relaxed in future versions of VLEACH.

## DATA REQUIREMENTS

The data requirements fall into four main categories.

### Chemical Parameters

These parameters describe the behavior of the contaminant in question. The parameters include the organic carbon distribution coefficient ( $K_{OC}$ ), Henry's constant ( $K_H$ ), the aqueous solubility, and the free air diffusion coefficient.

### Soil Properties

Dry bulk density, total porosity, volumetric water content, and organic carbon fraction.

### Site Properties

Recharge rate, depth to water, and the area of the polygon in question.

### Model Parameters

These parameters affect the way the calculations are performed, and include the time step length, cell dimensions, and output intervals.

## THEORY OF OPERATION

VLEACH is a relatively simple one-dimensional finite difference model. The code can simulate leaching in a number of distinct "polygons" during each run. The polygons may differ in soil properties, recharge rate, depth to water, or initial conditions. Each polygon is treated separately, and at the end of the run, an overall area-weighted groundwater impact is presented.

Each polygon is represented by a vertical stack of cells, reaching from the land surface to the water table. The mass of contaminant within each cell is partitioned among three phases: liquid (dissolved in water), vapor, and sorbed to solid surfaces. For simulation purposes, time is divided into user-specified discrete time steps. During each time step, three separate processes take place. Contaminant in the liquid phase is subject to downward advection; contaminant in the vapor phase is subject to gas diffusion; and finally each cell is re-equilibrated according to the distribution coefficients. Each process will be described in greater detail. All symbols used in the following equations are defined in Table 1.

Table 1 Equation Variable Definitions		
$M_T$	=	Total mass of contamination in a model cell [M]
$\Delta Z$	=	Thickness of cells in VLEACH calculation [L]
$n$	=	Total porosity of soil [dimensionless]
$\theta$	=	Water-filled porosity of soil [dimensionless]
$\rho_b$	=	Bulk density of soil [M/L <sup>3</sup> ]
$K_D$	=	Distribution coefficient for soil-water partitioning [L <sup>3</sup> /M]
$K_H$	=	Henry's constant for air-water partitioning [dimensionless]
$C_s$	=	Contaminant concentration in sorbed phase [M/M]
$C_l$	=	Contaminant concentration in the liquid phase [M/L <sup>3</sup> ]
$C_g$	=	Contaminant concentration in the gas phase [M/L <sup>3</sup> ]
$C_{INF}$	=	Contaminant concentration in infiltrating water [M/L <sup>3</sup> ]
$C_{NCELL}$	=	Contaminant concentration in water in bottom cell [M/L <sup>3</sup> ]
$C_{ATM}$	=	Contaminant concentration in atmospheric air above soil surface [M/L <sup>3</sup> ]
$C_{gw}$	=	Contaminant concentration in groundwater (with respect to gas phase exchange between water table and vadose zone [M/L <sup>3</sup> ])
$f_{oc}$	=	Fraction organic carbon in soil [dimensionless]
$K_{oc}$	=	Organic carbon partition coefficient [L <sup>3</sup> /M]
$D$	=	Effective diffusion coefficient [L <sup>2</sup> /T]
$D_{AIR}$	=	Free air diffusion coefficient [L <sup>2</sup> /T]
$q$	=	Darcian flux of percolating water [L/T]
In finite difference equations:		
$C_{i-1}^{t+\Delta t}$		
$C$	=	Refers to concentration of gas or liquid, depending on the equation [M/L <sup>3</sup> ].
$t+\Delta t$	=	Refers to the time step at which the concentration is calculated.
$i-1$	=	Refers to the cell number in which the concentration is calculated.

## INITIAL CALCULATIONS

The first calculations performed include unit conversions (all internal calculations are conducted in consistent units of grams, feet, and years) and calculations of  $K_D$  and  $D$ , the effective diffusion coefficient. The equations are as follows:

$$K_D = K_{oc} \times f_{oc}$$

$$D = D_{AIR} \times \frac{(n-\theta)^{10/3}}{n^2}$$

## LIQUID ADVECTION

Liquid advection is driven by the downward flux of recharging groundwater, according to the following equation:

$$\frac{\partial C}{\partial t} = \frac{-q}{\theta} \frac{\partial C}{\partial z}$$

For modeling purposes, the partial differential equation (PDE) is approximated by the following finite difference equation (FDE). The FDE is space-upward (in keeping with the asymmetric nature of advection), and time-centered (Crank-Nicholson).

$$\frac{C_i^{t+\Delta t} - C_i^t}{\Delta t} = \frac{-q}{2\theta\Delta z} \left[ (C_i^{t+\Delta t} - C_{i-1}^{t+\Delta t}) + (C_i^t - C_{i-1}^t) \right]$$

One FDE results for each cell, so NCELL similar equations must be solved simultaneously. VLEACH solves these equations in matrix form using the Thomas algorithm.

The mass fluxes at the top and bottom of the vadose zone are derived from the following equations:

$$J_{TOP} = Cq|_{z=0} = q C_{INF}$$

$$J_{BOTTOM} = Cq|_{z=DTW} = qC_{NCELL}$$

## GAS DIFFUSION

Gas diffusion is described by Fick's Second Law:



$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial z^2}$$

This PDE is converted to a space-centered, backward-difference FDE:

$$\frac{C_i^{t+\Delta t} - C_i^t}{\Delta t} = \frac{D}{(\Delta z)^2} (C_{i-1}^{t+\Delta t} - 2 C_i^{t+\Delta t} + C_{i+1}^{t+\Delta t})$$

Although space-centered (Crank-Nicholson) equation is intuitively more appealing, it led to unexpected stability problems not encountered with the backward-difference formulation.

The mass fluxes at the top and bottom of the vadose zone are derived from the following equations:

$$J_{TOP} = (n-\theta) D \frac{\partial C}{\partial z} \Big|_{z=0} = (n-\theta) D \frac{(C_{ATM} - C_1)}{\Delta z}$$

$$J_{BOTTOM} = (n-\theta) D \frac{\partial C}{\partial z} \Big|_{z=DTW} = (n-\theta) D K_H \frac{(C_{NCELL} - C_{gw})}{\Delta z}$$

## EQUILIBRATION

Equilibration among the three phases within each cell is performed by first converting the three phase concentrations to mass, summing to determine total mass, partitioning this mass among three phases, and finally converting back to concentrations. The equations are as follows:

$$M_T = \Delta z (\theta C_l + C_g (n-\theta) + \rho_b C_s)$$

$$C_g = \frac{M_T}{\Delta z \left( \frac{\theta}{K_H} + (n-\theta) + \rho_b \left( \frac{K_D}{K_H} \right) \right)}$$

$$C_l = \frac{M_T}{\Delta z (\theta + K_H (n-\theta) + \rho_b K_D)}$$

$$C_s = \frac{M_T}{\Delta z \left( \frac{\theta}{K_D} + (n-\theta) \left( \frac{K_H}{K_D} \right) + \rho_b \right)}$$

NOTE: l = liquid phase; g = gas phase; and s = sorbed phase.

## OUTPUT

The output consists of mass balance calculations and groundwater impact estimates. The mass balance calculations compare the change in mass within the profile to the calculated boundary fluxes, while the groundwater impact calculations are based on the downward flux at the water table, due to diffusion and advection.